The WELDING JOURNAL

MAY 1953

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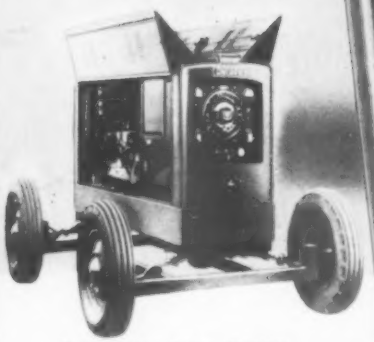

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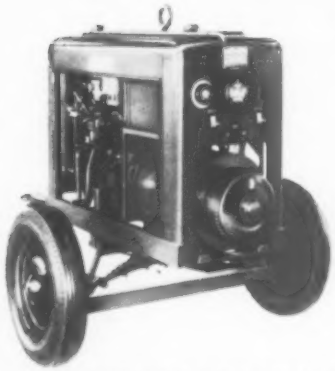

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The WELDING JOURNAL

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The WELDING JOURNAL

volume 32 May 1953 number 5

Production Welding of Steels by Gas-Shielded Arc Welding

Production welding procedures of mild and low-alloy steels by gas-shielded arc have been developed to the stage where it is competitive in cost and quality with older methods

by C. J. Sullivan

THE known fundamentals and operational characteristics of the Aircomatic Process have already been described in earlier issues of THE WELDING JOURNAL.[1,2] The earliest efforts in developing the Aircomatic Process were directed toward the joining of aluminum, where the need for improvement in welding processes was greatest. As our knowledge and experience with the process developed, it was extended to include stainless steels and copper alloys; and the process is stabilized to the point where it is now widely used in the joining of these materials. However, research and development in these fields are still continuing at a strong rate.

The need for quality improvement in the welding of carbon and low-alloy steels was not nearly so great, since considerable time and effort had been expended, with satisfactory results, in the development of existing processes, although the problems of porosity, undercut and cracking have by no means been entirely eliminated. However, the use of shielded arc electrodes and submerged arc welding is widespread practice and, because of the wide variety of electrodes available, most welding problems have a satisfactory solution. For this reason, it was apparent that for the Aircomatic Process to be accepted, it must do so almost entirely on the basis of economics, at the same time producing welds at least equal in quality to those produced by more conventional methods.

The most difficult problem encountered in the application of the Aircomatic process* to carbon steels has been the elimination of porosity, which has been largely eliminated by proper balancing of the chemical composition of the wire. For example, one wire only recently developed produces a sound deposit with good mechanical properties. The radiograph of a typical deposit is shown in Fig. 1, and the properties are listed in Table 1. The wide variation in impact properties is due to differences in deposition technique, with the higher values resulting from use of the stringer bead technique.

In their recent paper, Warren and Stout[3] presented an excellent study of the factors controlling porosity. They reported that mechanically produced voids occurred at high current densities and high welding speeds, and that these voids were always located at the deepest point of penetration. This phenomenon was recently observed in making a single-vee butt joint in $^1/_2$-in. plate, with a tight copper back-up. Close observation of the arc revealed that strong arc blow was forcing the arc cone back into the molten pool and that the arc force was sufficient to create and maintain a large void at the root. It was found that this effect could be eliminated by either of two methods: (1) relocation of the ground connection, which redirected the arc blow away from the pool, and (2) maintaining a space of approximately $^1/_{32}$-in. between the plate and back-up thus allowing the gas pressure to drain away from the root of the bead.

C. J. Sullivan is connected with the Air Reduction Sales Co., New York, N. Y.

Presented at the Thirty-Third National Fall Meeting, AWS, Philadelphia, Pa., week of Oct. 20, 1952. Closing date for discussion July 15, 1953.

* Shielded-inert gas-metal-arc welding. Abbreviated to inert-metal-arc.

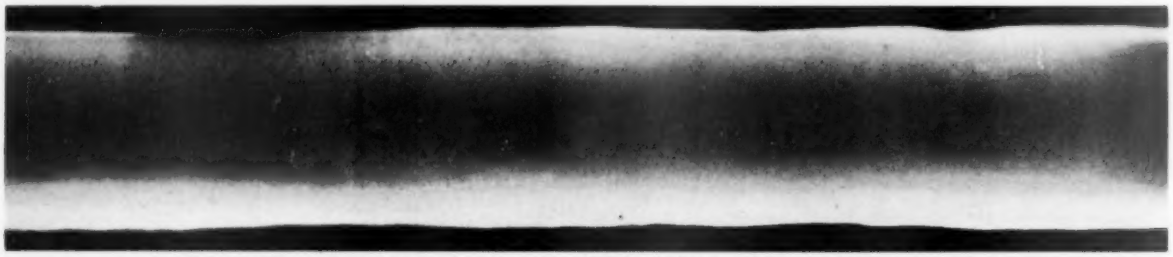


Fig. 1 Radiograph—weld made in $^1/_2$-in. mild steel plate with Airco A675 mild steel wire

Table 1—All-Weld-Metal Mechanical Properties

Yield strength, psi	60,000
Tensile strength, psi	72,000
Elongation (2 in.), %	22
Impact (keyhole Charpy)	
Range, ft-lb	33–48
Average, ft-lb	38$^1/_2$
Hardness, BHN	170–215

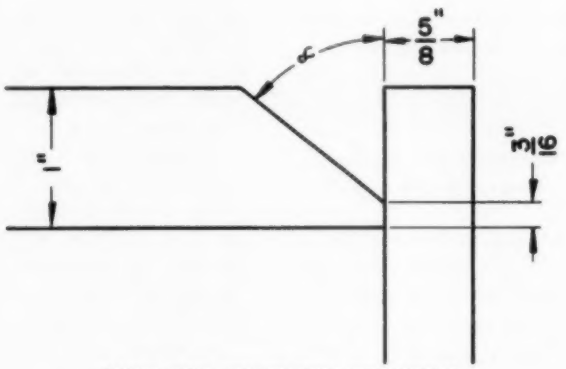
The next most difficult problem has been the elimination of undercut adjacent to the weld bead. It was found that the addition of a small percentage of oxygen to the inert gas has the effect of minimizing or eliminating this condition. However, it has also been found that the effectiveness of the oxygen varies from plate to plate.

Although the use of the Inert-metal-arc process for joining steel cannot yet be considered stabilized in the same sense as the more conventional processes, it is being applied in several industries, and it seems pertinent to present some examples of successful applications to illustrate graphically the possibilities of the process.

Figure 2 shows a sketch of a corner joint, a production item fabricated from hot-rolled mild steel. This joint is normally welded with stick electrodes, $^3/_{16}$-in. type E6012 at 290 amperes for the first pass, and $^1/_4$-in. type E6020 at 400 amperes for subsequent passes. Penetration through the nose is not obtained in production and a $^1/_4$-in. fillet is deposited on the inside of the corner as a seal bead, although this bead was not considered in the comparison. A bevel of 45 degrees is normally used.

A comparative study of this joint was conducted by the fabricator comparing conventional manual methods with the Inert-metal-arc process, using $^1/_{16}$-in. steel wire in a manually operated No. 20 Aircomatic gun. In preliminary trials, it was found that the included angle could comfortably be reduced to 35 degrees, thus reducing the number of passes required while still producing a penetration pattern equivalent to that of conventional methods.

The reported data indicate that the joint was fabricated with the Inert-metal-arc process in less than half the time required for the conventional method, using only half as much wire. The total cost of the assemblies, as reported in the data, do not indicate any economic



DATA FOR COMPLETE ASSEMBLY

	Aircomatic	*Conventional Shielded Arc*
Angle α, deg	35	45
Number of passes	4	5
Weight of electrode used, lb	9.99	19.9
Argon used, cu ft	3.6	...
Arc time, hr	0.90	1.89
Total time, hr	1.06	2.85
Duty cycle, %	85.0	66.4
Labor rate per hour	$1.38	$1.38
Direct labor	$1.46	$3.94
Materials	$5.90	$2.19
Total cost (excluding overhead)	$7.36	$6.13

Fig. 2 Comparative data for corner joint

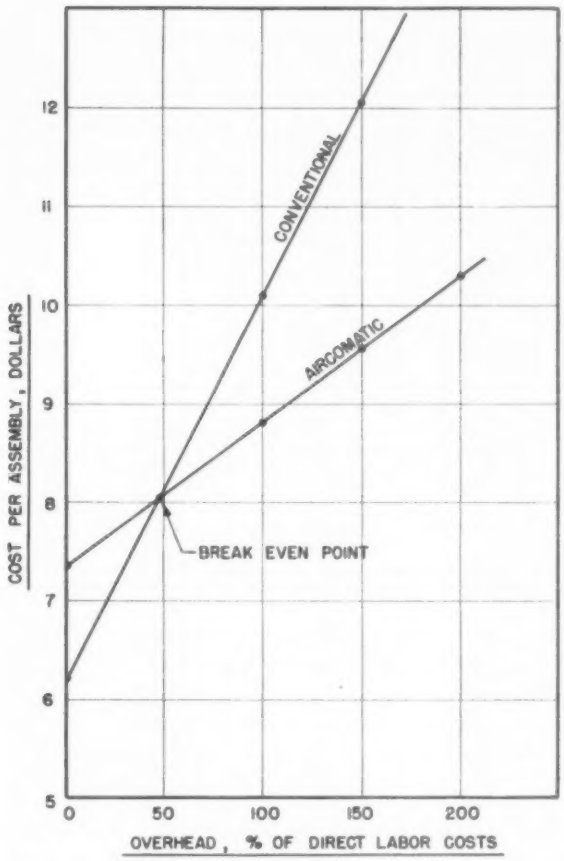


Fig. 3 Variation of total cost with overhead charges

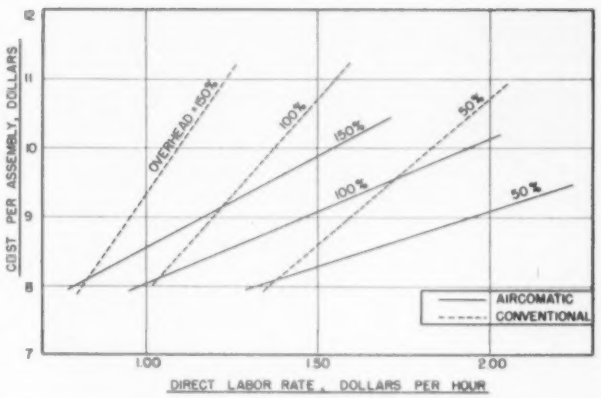


Fig. 4 Variation of total cost with direct labor rate for various overhead rates

advantage for the Inert-metal-arc process. However, it should be noted that these costs do not include an overhead charge and, when overhead charges are considered as illustrated in Fig. 3, the break-even point occurs when overhead charges equal about 50% of the direct labor rate. At overhead rates greater than this, the Inert-metal-arc process shows an increasing economic advantage. At 100%, Inert-metal-arc shows a reduction in cost of 12% and at 150%, a reduction of about 20%.

Variations in direct labor rate will also affect the comparison. In Fig. 4, the effects of variations in labor rate on the two processes are compared at 50, 100 and 150% overhead charges, respectively. These indicate that lower labor rates favor the conventional method, while higher labor rates favor Aircomatic, although the break-even point varies inversely with overhead charges.

Recently, a fabricator conducted an investigation designed to compare the Inert-metal-arc process with the

Table 2—Fillet Joints, Comparative Data—Horizontal Position

Fillet sizes, in.	*Process*	*Electrode size, in.*	*Passes*	*Current, (amp)*	*Burn-off rate, (ipm)*	*Inert gas, (cfh)*	*Welding speed, (fph)*
3/16	Conventional	E6012, 5/32	1	150	10.0	..	40.0
3/16	Aircomatic	A650, 1/16	1	320	150	40	120.0
1/4	Conventional	E6012, 3/16	1	190	9.1	..	31.65
1/4	Aircomatic	A650, 1/16	1	325	150	40	70.5
3/8	Conventional	E6012, 1/4	1	265	8.0	..	20.0
3/8	Aircomatic	A650, 1/16	1	335	155	40	32.3
1/2	Conventional	E6012, 1/4	2	270	8.0	..	11.0
1/2	Aircomatic	A650, 1/16	3	340	155	40	17.0
5/8	Conventional	E6012, 1/4	4	270	8.1	..	7.50
5/8	Aircomatic	A650, 1/16	3	335	155	40	12.3

Table 3—Fillet Joints, Comparative Data—Flat Position

Fillet sizes, in.	*Process*	*Electrode size, in.*	*Passes*	*Current, (amp)*	*Burn-off rate, (ipm)*	*Inert gas, (cfh)*	*Welding speed, (fph)*
3/16	Conventional	E6020, 5/32	1	170	12.0	..	50.0
3/16	Aircomatic	A650, 1/16	1	336	150	40	110.0
1/4	Conventional	E6020, 3/16	1	220	11.0	..	38.2
1/4	Aircomatic	A650, 1/16	1	320	150	40	70.0
3/8	Conventional	E6020, 1/4	1	300	9.4	..	24.0
3/8	Aircomatic	A650, 1/16	1	340	155	40	38.8
1/2	Conventional	E6020, 1/4	2	300	9.4	..	13.35
1/2	Aircomatic	A650, 1/16	1	335	155	40	19.3
5/8	Conventional	E6020, 1/4	2	305	9.5	..	9.25
5/8	Aircomatic	A650, 1/16	2	340	155	40	14.1

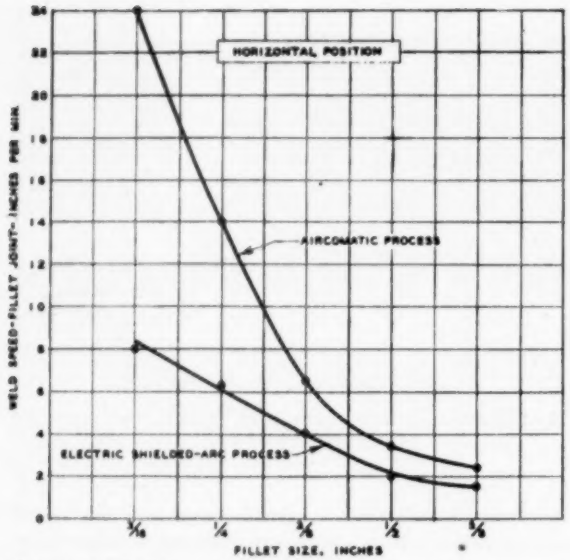


Fig. 5 Comparison of fillet welding speeds for conventional and Inert-metal-arc welding (horizontal position)

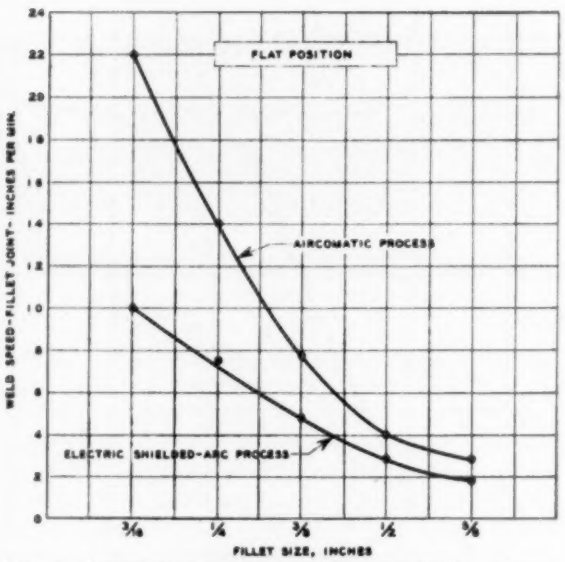


Fig. 6 Comparison of fillet welding speeds for conventional and Inert-metal-arc welding (flat position)

conventional shielded arc in the welding of fillets. The study included $^3/_{16}$-, $^1/_4$-, $^3/_8$-, $^1/_2$- and $^5/_8$-in. fillets in mild steel, welded with the No. 20 Aircomatic gun and standard manual arc-welding equipment. All samples were welded in the horizontal and flat positions.

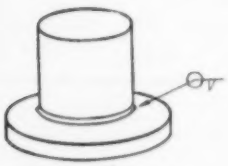
The accumulated data are listed in Tables 2 and 3 and Figs. 5 and 6. The results for both welding positions are essentially similar in that the Inert-metal-arc process shows a decreasing speed advantage with increasing fillet size. Thus, for the smaller fillet sizes, Inert-metal-arc shows a two- to three-time speed advantage, but as the fillet size increases, this drops off to about one and one-half.

However, it should be noted that the Inert-metal-arc fillets were made by using a single wire size throughout the series, so that the deposition rate was essentially constant. On the other hand, the conventionally welded joints were made with progressively larger electrodes, with the result that the deposition rate increased with the larger fillet sizes. This would also have been true of the Inert-metal-arc process if larger wires, such as $^5/_{64}$ and $^3/_{32}$ in., had been used.

As a continuation of the above study, a cost analysis was made of a hypothetical joint which consists of a flange joined to a cylindrical section by means of a fillet, welded in the horizontal position. It was necessary to assume values for several quantities, such as duty cycle, deposition efficiency and an adjustment for down time, and these are listed in Table 4.

The costs for materials and power for the Inert-metal-arc process are considerably higher than for the conventional method, but labor costs are much lower. If the sums of material and direct labor costs are considered without an overhead charge, the Inert-metal-arc process shows a diminishing advantage throughout the range. The addition of an overhead charge assessed at 100%

Table 4—Comparative Costs for a Hypothetical Welding Application Costs per 100 Assemblies



Assumptions	*Aircomatic process*	*Conventional shielded arc*
Duty cycle, %	85	50
Deposition efficiency, %	95	60
Weld length, ft	3	3
Weld position	Horizontal	Horizontal
Down Time, %	15	15

Fillet size, in.	*Material and power** Aircomatic	*Material and power** Conventional	*Direct labor* Aircomatic	*Direct labor* Conventional	*Sum of material and direct labor costs* Aircomatic	*Sum of material and direct labor costs* Conventional	*Total cost for 100 assemblies,†* Aircomatic	*Total cost for 100 assemblies,†* Conventional
$^3/_{16}$	$ 13.50	$ 4.65	$ 6.75	$ 34.41	$ 20.25	$ 39.06	$ 27.00	$ 73.47
$^1/_4$	22.94	7.88	11.48	43.48	34.42	51.36	45.90	94.84
$^3/_8$	50.99	18.01	25.07	68.82	76.06	86.83	101.13	155.65
$^1/_2$	86.53	32.80	47.62	125.14	144.15	157.94	191.77	283.08
$^5/_8$	133.66	48.65	65.82	183.53	199.48	232.18	265.30	415.71

* Includes cost of electrodes and inert gas. Aircomatic wire price $0.25 per lb and argon price $0.08 per cu ft. Electrode cost $0.13 per lb and stub end loss 2 in. Power cost $0.02 per kwhr.

† Includes an overhead charge equal to 100% of the direct labor charges.

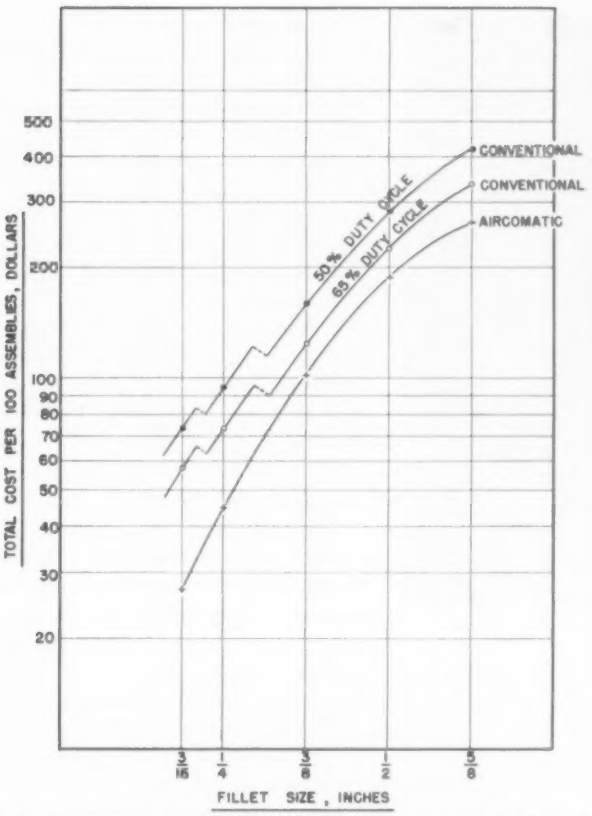


Fig. 7 Comparison of total costs for conventional and Inert-metal-arc manual welding. Overhead assessed at 100% of direct labor rate

of the direct labor rate considerably increases this advantage.

Because of the variation in duty cycle in conventional welding existing in various shops throughout the country, it was considered advisable to compute the costs resulting from a higher value. In Fig. 7, the total costs for the Inert-metal-arc process are compared with the conventional method at 50 and 65% duty cycles, all including an overhead charge of 100% of direct labor charges. It will be seen that the economic advantage of the Inert-metal-arc process has been reduced but is still appreciable.

Recently a manufacturer of steel tubing and other products was confronted with the problem of welding

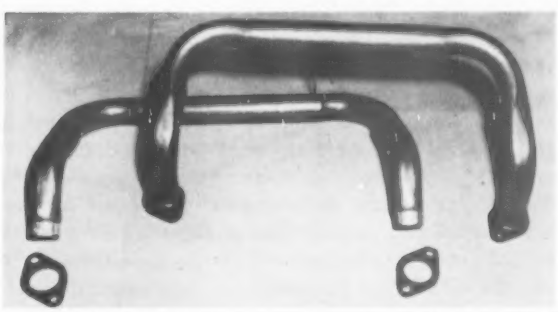


Fig. 8 Mild steel cross-over pipes, one with Aircomatic welded flanges

Fig. 9 Close-up of jig, showing shortened Aircomatic gun assembly

flanges on both ends of a bent and formed section of thin-walled mild steel tubing. The components and a completed assembly are shown in Fig. 8. The tubing was $1^5/_8$ in. in diameter, with an 18-gage wall, and the flange was $^5/_{16}$ in. thick.

A production setup was arranged by mounting the barrel of a manual Aircomatic unit in a jig designed to hold and rotate the tube-and-flange assembly during welding, as shown in Figs. 9 and 10. The dismounted

Fig. 10 Inert-metal-arc welding flange to one end of tube in jig

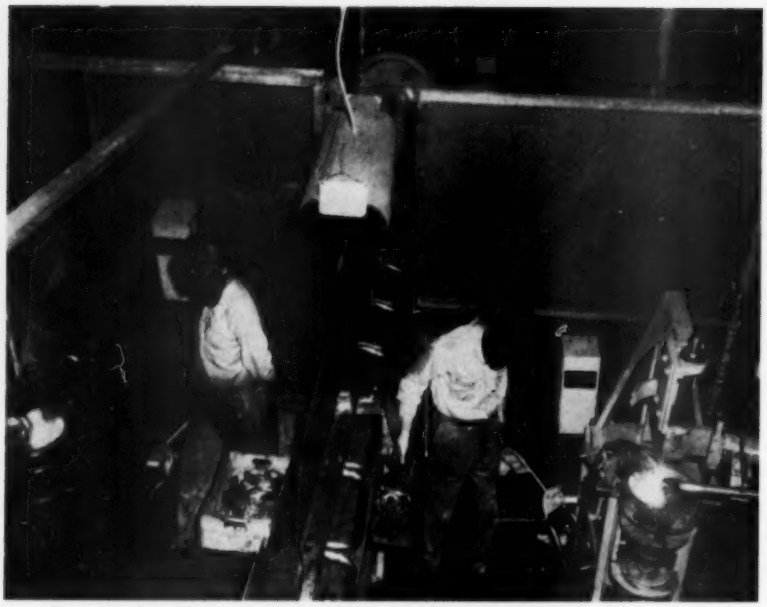


Fig. 11 Inert-metal-arc welding booth, showing automatic setups

handle of the gun was held in the hand of the operator controlling the operation. Two of these jigs were constructed, one for welding each flange. In production, one flange was welded in the booth at the right (Fig. 11) and the part was then passed over to the left booth, where the other flange was welded.

The welding was accomplished at 350 amperes at 25 volts, using 40 cfh of argon. The wire used was $^1/_{16}$-in. diameter mild steel, feeding at a rate of 192 ipm. Each weld was made at 60 ipm, being completed in 5 seconds and requiring 16 in. of wire per weld. Each complete assembly required 32 in. of wire and about $^1/_4$ cu ft of argon.

There has also been a fair amount of work done on joints in light gage material; for example, in the girth welds of a mild steel liquid container. This container was formed from two pressed halves of 20-gage steel, which were then butted together at the midsection and welded. A collapsible copper back-up was used to support the joint during welding.

Mild steel wire, $^1/_{16}$ in. in diameter, was used at about 460 amperes and the weld was made at 80 ipm. These containers were all subjected to leak tests in which less than 1% failed and these failures were attributed to malfunctioning of the back-up. After the majority of this group of drums had been run, a $^5/_{64}$-in. diameter wire was substituted for the $^1/_{16}$-in. wire and it was found possible to increase the weld speed to 100 ipm, using 550 amperes. These conditions also gave excellent results.

From the foregoing, it is evident that although there will be considerable development in the future, the Inert-metal-arc welding of mild steel and low-alloy steels can no longer be considered a laboratory curiosity. It is now fully capable of producing welds equivalent in quality to conventional methods at greater speeds and lower costs.

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Gases Produced by Inert Arc Welding

by John J. Ferry and Gordon B. Ginther

THE health hazards associated with welding processes were investigated quite thoroughly 10 to 20 years ago and were shown to be comparatively minor under normal conditions. Since that time several new welding processes, such as inert arc, atomic hydrogen, submerged arc and arc welding with low-hydrogen type coatings, have come into common usage and the potential hazards have never been thoroughly investigated. The increasing importance of these processes is best illustrated by the fact that 30% of the country's production of helium is used by industry, mostly for inert arc welding.[1]

An investigation of gases and vapors which may be produced by the inert-arc welding process has been made. Two different problems were investigated, the formation of ozone and nitrogen oxides, and the decomposition of trichloroethylene vapor in the vicinity of the arc. This latter condition was studied due to the fairly common procedure of degreasing materials prior to welding and because of the complaints which frequently arise when this is done.

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SAMPLING PROCEDURES

Because of difficulties involved in prolonged sampling in the shops, all tests were made in the welding laboratory. The standard inert arc holder and power source was used. The power was direct current and straight polarity. The electrode was tungsten and the arc was struck to a watercooled copper block. During tests the electrode holder was clamped to maintain an arc of normal length. No filler metal was used, tests being made only on the effect of the arc. Welding grade helium and argon were used of 99.99 and 99.98% purity, respectively, at a rate of 15 cfh. In some cases normal gas flow was doubled to determine if this produced any unusual effect.

The currents tested, 55 and 110 amp with 40 mil and 3/32-in. electrodes, were selected as those most commonly used in this plant. In the trichloroethylene decomposition tests, 110 amp was used exclusively.

Ozone samples were collected by means of a fritted glass bubbler containing 30% potassium iodide, and ozone determined by titration with 0.01 *N* sodium thiosulfate.[2] Although higher oxides of nitrogen may interfere with this method, it was felt that the results would, if not, accurate, at least be on the high side. Sample volumes were approximately 500 liters collected over a period of 18 min.

Oxides of nitrogen samples were collected by aspirating air into a 4-liters bottle. Acid peroxide was placed in the bottle and the determinations made by the phenol disulfonic acid method.[3] Both the above type samples were collected in the approximate breathing zone of the welder, at a point 1 to 2 ft from the arc.

Table 1—Ozone and Nitrogen Oxides

Gas used	*amp*	*ozone, ppm*	*Nitrogen oxides, ppm*
Argon	55	0.1	...
Helium	55	0.1	...
Argon	110	0.5	...
Argon	110	0.6*	...
Helium	110	0.1	...
Helium	110	0.1*	...
Helium	110	0.0*	0.3*
Argon	110	0.4	2.5
Argon	110	0.6	3.0*
Helium	110	...	0.5*
Helium	110	...	0.3
Argon	110	...	3.0*
Argon	110	...	2.5

* Normal rate of gas flow was doubled.

For trichloroethylene decomposition, a cardboard box, 16 in. on each side, was placed with the open side toward, and about 12 in. from, the arc. An evaporating dish containing trichloroethylene and varying numbers of paper wicks was placed in the box. Adjustment of these wicks permitted a fair degree of control of the vapor concentration. Three plastic sampling tubes were admitted through holes in the top of the box and extended to about 3 in. from the top. One of these tubes was connected to the Davis Halide Meter, and the values noted on the meter interpreted as the total trichloroethylene available at this point in the box. Immediately adjacent to the first tube, a second tube was connected to a fritted glass bubbler and to a suction pump. Before the arc was started, the pump was operated at a rate of 28 lpm and the desired vapor concentration established. Samples were collected for approximately 18 min in standard alkali and the resulting solution back titrated with standard sulfuric acid to determine total acidity. The solution resulting from titration was then made distinctly acid, silver nitrate added and the silver chloride determined gravimetrically.

Table 2—Trichloroethylene Decomposition

Gas used	*Trichloroethylene ppm*	*Total free acidity**	*Chlorides**	*Phosgene,† ppm*
Argon	30	56.0	31.0	35
Helium	30	4.0	3.0	4
Argon	300	168.0	90.0	350
Argon	25	1.0	1.0	3‡
Argon	25	70.0	35.0	130
Argon	0–10	20.8	10.6	175

* Calculated as milligrams of hydrogen chloride per cubic meter of air sampled.

† Phosgene values are not directly related to trichloroethylene concentrations.

‡ Arc shielded from trichloroethylene by glass funnel.

Phosgene was determined by the method described by the Department of Scientific and Industrial Research of Great Britain.[4] The efficiency of the scrubber to remove hydrogen chloride, etc., was checked after each series of tests. The specificity of these tests was confirmed by test papers using the nitroso reagent.[5] Phosgene samples were initially collected at a point in the lower front edge of the box, on the theory that the results would be too low to be important. Because of the astonishingly high values found, these tests were repeated, sampling from the third tube adjacent to the halide meter with closer correlation to trichloroethylene concentrations. The results of the second series of tests are shown in Table 3.

Table 3—Phosgene

Gas used	*Trichloroethylene, ppm*	*Phosgene produced, ppm*
Argon	0–15	45
Argon	60	140
Argon	100	180
Argon	140	280
Helium	30	6
Helium	30	4

OBSERVATIONS

During the tests for ozone, its odor was very distinct but not objectionable nor irritating.

No typical ozone odor was noticed during the trichloroethylene tests. There was, however, a very strong, irritating and disagreeable odor, somewhat reminiscent of trichloroacetic acid. This odor was produced even at a distance of several feet the instant the arc was struck when trichloroethylene vapor was present in the general atmosphere. The odor was not produced when the ordinary metallic arc was used in

the presence of trichloroethylene. When a Pyrex glass funnel was placed between the arc and the trichloroethylene, no such odor was noticed.

Ozone and Nitrogen Oxides

DISCUSSION

The results indicate that the ozone concentrations, while within the range that are sometimes considered irritating, were below the generally accepted threshold limit of one part per million. The oxides of nitrogen were well within safe limits. Whether these results would also be true for other forms of inert arc welding, using reversed polarity and alternating current, will have to be established experimentally. Results do indicate that higher amperage will probably increase ozone formation.

It is interesting to note that in every case argon produced more ozone, nitrogen oxides and trichloroethylene decomposition products than did helium. An increase in gas flow gave a similar though much smaller increase. It is felt that these latter phenomena are related to spectra of the respective gases. Unfortunately no information appears to be available in the literature to prove or disprove such a theory. Recent work in the field of analytical spectroscopy does indicate a greater intensity of emissent energy when an arc is operated in a helium or argon atmosphere,[6] and helium is known to have a much greater spectral emission and absorption than argon in the ultraviolet range.[7]

Trichloroethylene Decomposition

Trichloroethylene vapor in the vicinity of the arc was decomposed, the reaction starting instantly the arc was struck. While the correlation between trichloroethylene concentration and phosgene shown in Table 3 is obviously inaccurate, presumably because of limitations of the analytical methods used, the results do indicate that a large amount of the trichloroethylene is converted to phosgene. Other decomposition products were not identified. It is assumed that hydrogen chloride was present, but it is interesting to note that the total free acidity was just about twice that accounted for as hydrochloric acid by gravimetric determination of the chlorides. It appears that either a nonhalogen acid or a halogen acid such as chloroacetic which is not readily hydrolyzed was also present.

It is easy to conceive of a shop atmosphere containing 20 to 30 ppm of trichloroethylene, well below the threshold of odor, as a result of degreasing or other cleaning processes. It would not be unreasonable to assume, particularly if argon is used, dangerous concentrations of phosgene or other vapors being produced. Fortunately, the objectionable, irritating odor produced at the same time would probably discourage even the hardiest welder from continuing long on the job.

Shielding of the arc by means of a Pyrex glass funnel practically eliminated the decomposition effect. When a small amount of trichloroethylene vapor in a sealed quartz tube was exposed to the radiation of a therapeutic ultraviolet lamp for a few seconds, decomposition took place with acid and phosgene being produced, accompanied by the same odor formed at the arc. It is apparent that the action is photochemical with decomposition being caused by radiation from the arc, rather than by actual contact of the trichloroethylene vapor with the arc. This fact is of particular importance in providing control measures. It would appear that local exhaust ventilation at the arc would be of little value, since in the presence of even minute quantities of trichloroethylene, the decomposition products would be produced at the welder's breathing zone. Possibly a partial shield around the arc to prevent spread of radiation would be of greater value.

CONCLUSIONS

Oxides of nitrogen were not produced in significant concentrations by the inert arc-welding process studied.

Ozone was produced in significant concentrations, possibly in the irritating range, but below the threshold limit of 1 ppm.

Trichloroethylene vapor was decomposed, producing phosgene and other products. Such decomposition may produce dangerous concentrations of vapors from trichloroethylene concentrations well below the odor threshold.

The use of argon rather than helium in the torch significantly increased the formation of ozone, nitrogen oxides and trichloroethylene decomposition products.

The reaction producing the various vapors and gases determined appeared to be photochemical, caused by radiation from the arc. This should be considered in planning control measures.

This investigation was made possible through the advice and assistance of the Welding Section, Schenectady Works Laboratory.

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Automatic Field Welding of Girth Joints of Large Storage Tanks

Development of a carriage and other pertinent details for automatically making submerged arc welds in a horizontal position in the fabrication of large storage tanks

by Perry C. Arnold

MANY years ago the Chicago Bridge and Iron Co. learned that it was feasible, with the submerged-arc process, to deposit weld metal horizontally on a plate held in a vertical position. This fact was learned while running some fillet weld tests with an automatic machine. The operator in guiding the machine raised the tip too high and instead of making a fillet weld, he deposited a horizontal bead on a vertical plate. See Fig. 1.

This was the conception of the idea that, if weld metal could be deposited horizontally on a vertical plate, then it could also be deposited in a horizontal butt joint. We found that several manufacturers of welding equipment were willing to furnish welding heads for performing this type of work, but that no one had developed a suitable carriage for doing girth welding. Consequently, we decided to develop a carriage and other pertinent details that would make the automatic welding of girth joints possible and practical.

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To be presented at the National Spring Meeting, AWS, June 16-19, Houston, Tex.

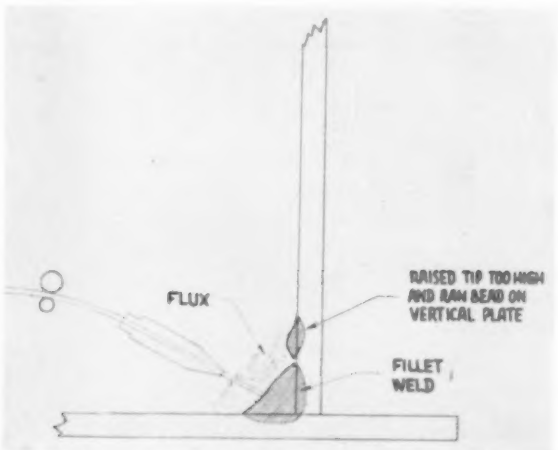

Fig. 1 Making of first automatic weld on vertical plate

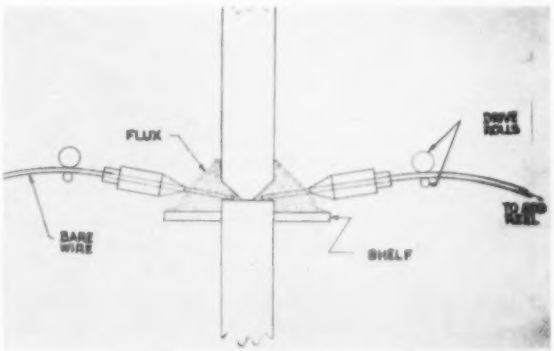

Fig. 2 Automatic girth welding

By early 1949 a fully automatic girth welding machine had been developed and assembled and sample welds made. The essential parts of an automatic girth machine are a powered variable speed carriage on which can be mounted two fully automatic welding heads, power for operating the welding heads and a means of supporting the flux during welding. Figure 2 shows a schematic drawing of two welding heads arranged so as to weld both sides simultaneously. The tips may be spaced either directly opposite each other or several inches apart. The tip spacing, together with the current setting, determines the depth of penetration of the weld metal. This equipment together with the proper guiding devices, reels, electrical controls, etc., is compactly mounted on a carriage that travels around the tank using the accurately machined upper edge of the shell plate as a track. Figure 3 shows one side of the automatic girth welding machine as it sits astraddle a shell plate. Preheating torches precede each welding tip and bring the abutting plate edges up to approximately 300° F prior to welding. It was found advisable to preheat in order to slow up the cooling rate of the weld metal, eliminate any moisture present in the joint and to help clean the plate edges by the principle of flame cleaning and pressuring.

After the first unit was built there followed a period of development and testing which was long and time

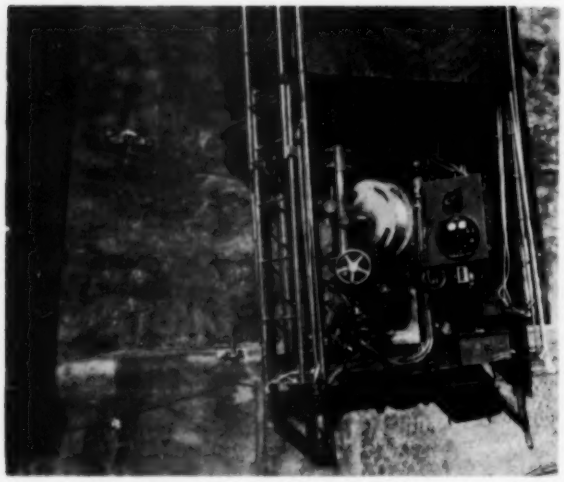

Fig. 3 View of one side of an automatic girth welding machine

consuming due to the many variables involved. Some of the variables that required evaluation were: (*a*) design of the welding groove, (*b*) rate of travel, (*c*) current settings for plate thicknesses from $^1/_4$ to $1^1/_2$ in., (*d*) welding of the sides at different times or simultaneously, (*e*) size and type of electrodes, (*f*) grade and size of flux, (*g*) distance of one electrode behind the other, (*h*) angle of inclination of electrode into puddle, (*i*) arc length or voltage settings. It is quite apparent that any change in any one or more of these variables changes the bead contour, penetration, amount of metal deposited and the smoothness and soundness of the weld. In order to ascertain the best value of each variable a great many test plates had to be made and many pages of data taken. This testing took the better part of a year and the services of many talented men.

Fig. 4 First two tanks with girth joints automatically welded

By January 1950 the required preliminary work was completed and the automatic girth welding machine was taken to the field. During the months of January and February the girth joints of two 154-ft diam tanks at Joliet, Ill., were automatically welded. Figure 4 shows these two tanks which, as far as we know, are the first in the world to have had their girth joints welded by the submerged-arc process. The quality of the welding in these joints was good and not too much mechanical trouble was experienced. Figure 5 shows a close up of the girth welding. Approval was given immediately for the construction of additional units.

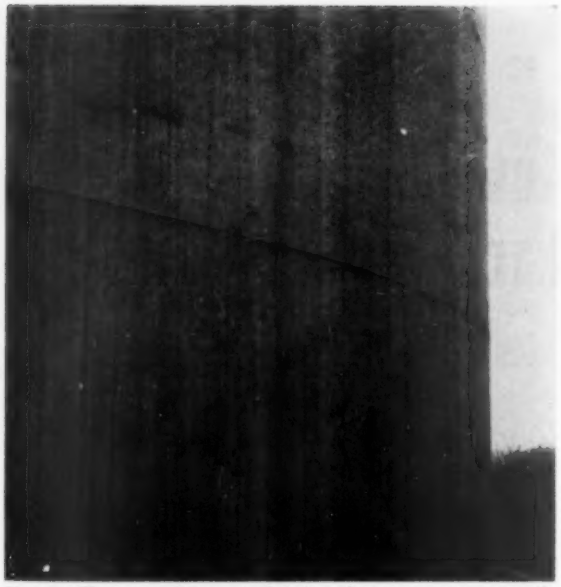

Fig. 5 Close up of first girth joint that was automatically field welded

Today, with over thirty units in operation, our company in general uses the automatic machine to field weld the girth joints of tanks 100 ft in diameter or over and many tanks of smaller diameter. Figure 6 shows the automatic machine in operation on a 120-ft diam tank recently erected at Salt Lake City, Utah. Figure 7 is a view of the same tank after completion.

In our laboratory and field use of the girth welding machine, many reasons were found for preferring the submerged arc weld over the customary hand weld. First of all was noted the reduction of residual stresses

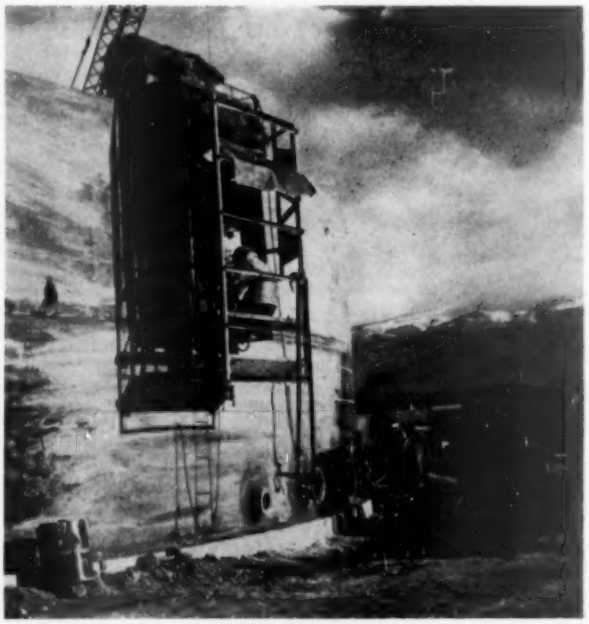

Fig. 6 Automatic machine in operation on a tank at Salt Lake City, Utah

Fig 7 Completed automatically welded tank at Salt Lake City, Utah

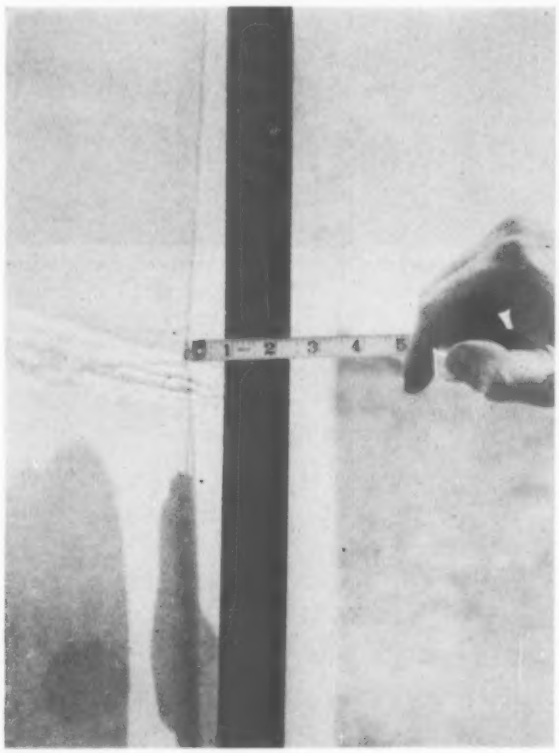

Fig. 8 Banding of girth joint manually welded

in the girth welds. Figure 8 shows a girth joint that was welded manually with E6010 electrodes. Note the banding caused by the shrinkage of many, small, manually deposited weld beads. In general, the more beads deposited in a joint, the greater will be the longitudinal shrinkage. Figure 9 shows another tank that was manually welded. The noticeable banding or inward movement of the joint is caused by shrinkage stresses. Thus the circumferential stresses in such a joint must be very high. Figure 10 shows a joint

Fig. 9 Banding of girth joints manually welded

welded automatically with only one bead deposited on each side. Note the absence of banding and the smoothness of the shell.

Figure 11 shows a joint welded automatically where the plates were considerably heavier requiring two beads to be deposited on each side. Again note the absence of banding. Figures 12 and 13 show the absence of banding on some completed tanks where the automatic was used. With the automatic machine welding both sides simultaneously with adequate preheat and the joint completed with relatively few passes, distortion is held to a minimum, as evidenced by no banding and the circumferential residual stresses must be correspondingly small.

The importance of making a high quality girth weld with low residual stresses is not fully appreciated by many. In order for a weld to cause the seam to move inward, termed banding, the weld and a portion of the heat-affected zone, due to shrinkage, exert a high tensile force on the adjacent material. The adjacent

material in turn has to resist this tensile force so, therefore, it exerts a compressive force to balance the load system. Recognizing that there is always some compression in a plate to offset the high tension in the weld, you can then understand that the weld must

Fig. 10 Absence of banding on tank automatically welded

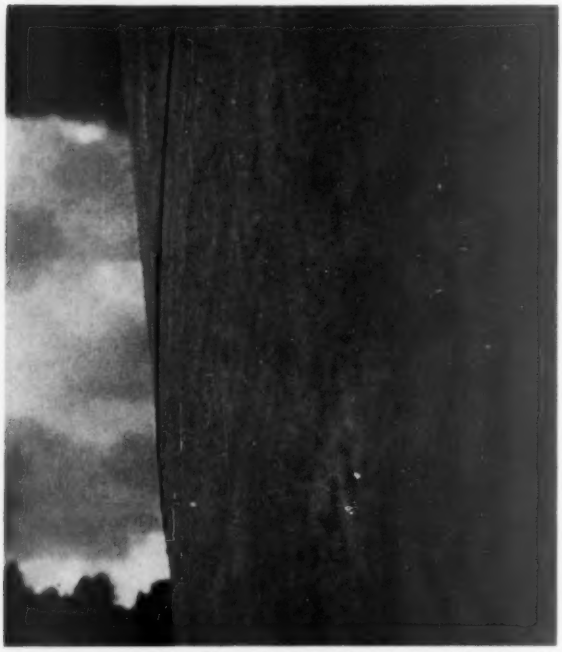

Fig. 12 Automatically welded girth joint. Smooth, no banding

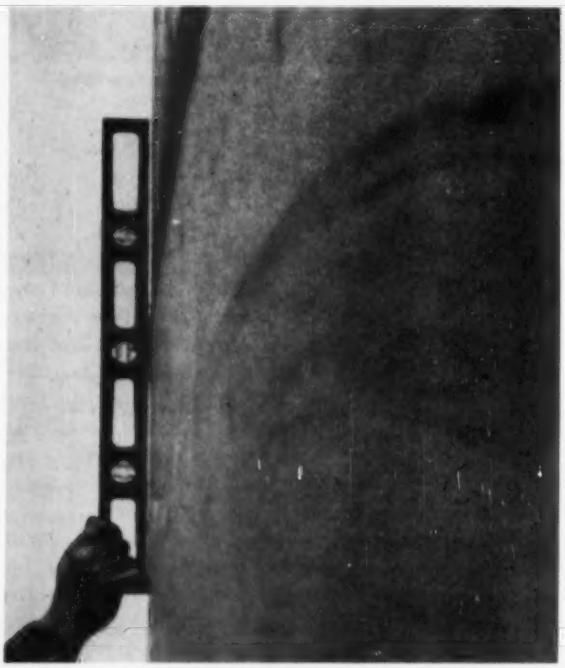

Fig. 11 Absence of banding on tank automatically welded

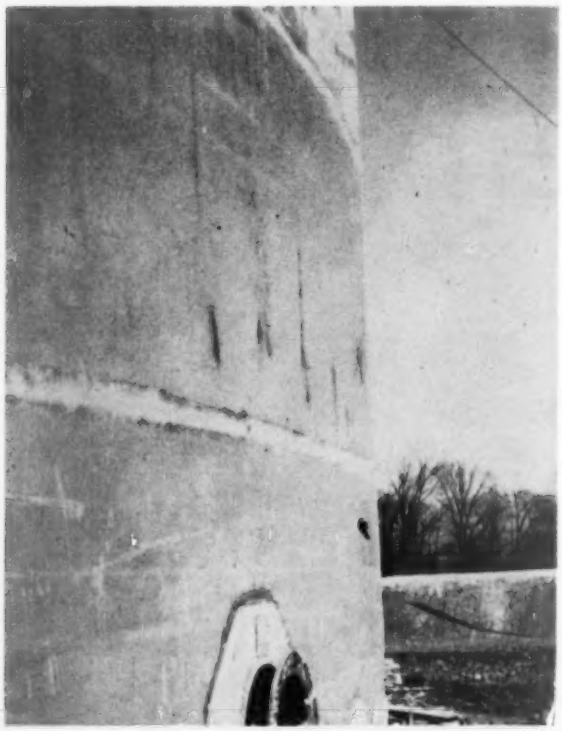

Fig. 13 Automatically welded girth joints. Note absence of banding

plastically flow until the plate comes into tension to carry the load from the tank contents. Carrying this reasoning further, when a tank is filled with water for a test, the weld must be ductile enough, at a given temperature, to plastically deform so that the surrounding plate which was in compression, due to the shrinkage stresses, may go into tension and carry its share of the load. If the weld does not have the ability to plastically deform, but fails, the resulting crack will lie in a plane at right angles to the weld. A crack forming perpendicularly to the axis of a girth weld lies in a vertical plane which is also the plane wherein lie the principal stresses from the tank contents. Thus a crack started from the effect of the residual stresses may be propagated by the principal stresses. It seems logical that the lower the residual stress and the higher the low-temperature impact strength and ductility of the weld metal, the safer the vessel becomes.

The foregoing discussion has attempted to show that the residual stresses in a girth joint, automatically welded, are lower than those in one manually welded. Let us look at the other physical characteristics of the automatic weld to see if they are favorable to good performance. We all know, from the published literature that the performance of hydrogen-free weldments has been excellent and the incidence of cracking low. It is recognized that a submerged arc weld is essentially hydrogen-free since the arc is completely surrounded by an all-mineral flux. This hydrogen-free, low-carbon, high-manganese weld metal, plus preheating and slow cooling, accounts for the high impact properties of the weldments made with the girth welding machine. Listed below are the results, as found by an outside laboratory, of the impact strength of the weld metal and the parent material of some tests performed independently of our company. Material was $1^{1}/_{32}$- and $^{7}/_{8}$-in. plate to ASTM specification A283 Gr. C. The weld was made in three passes from each side, with both sides welded simultaneously. The chemical compositions of the material and weld metal were as shown in Table 1.

Table 1

	C, %	*Mn*, %	*P*, %	*S*, %	*Si*, %
$^{7}/_{8}$-in. plate	0.23	0.56	0.012	0.024	0.01
$1^{1}/_{32}$-in. plate	0.11	0.35	0.009	0.023	0.01
Weld metal	0.11	0.90	0.015	0.034	0.24

Six keyhole Charpy specimens were machined from each of five locations in the thickness of the weld metal. The five locations were chosen as follows:

No. 1—At the surface of the joint, on the leading arc side

No. 2—Midway of surface to center, on the leading arc side

No. 3—Center of the joint

No. 4—Midway of center to the surface, on the trailing arc side

No. 5—At the surface of joint, on the trailing arc side

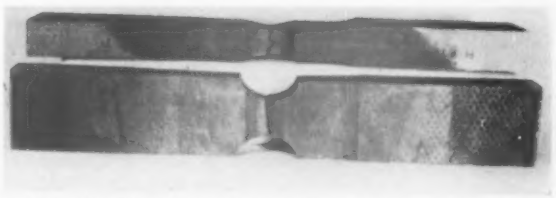

Fig. 14 Tensile specimens of automatic girth weld

Fig. 15 Free-bend specimens of automatic girth weld

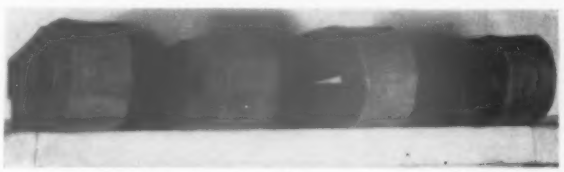

Fig. 16 Face view of specimens shown in Fig. 15

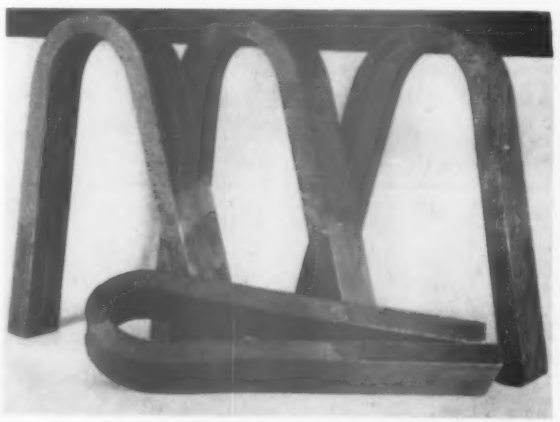

Fig. 17 Guided-bend specimens of automatic girth weld

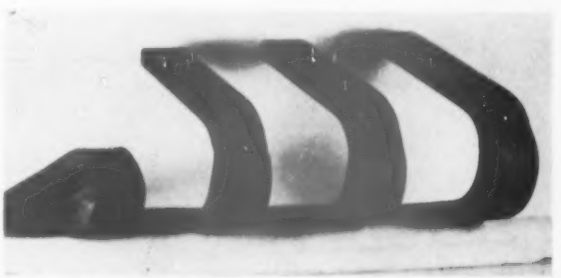

Fig. 18 Face view of guided-bend specimens of automatic girth weld

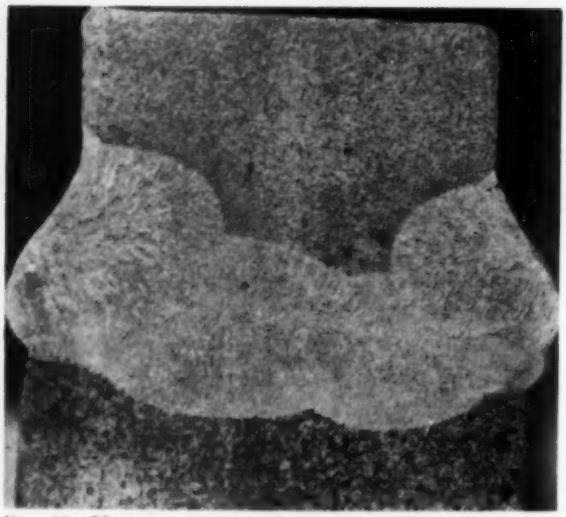

Fig. 19 Macro-specimen of automatically welded girth joint

All specimens were taken so that their longitudinal axis lay perpendicular to the girth joint and the axis of the hole lay perpendicular to the surface of the plate. In addition, Charpy specimens were taken from both the top and bottom plates. Tests were made in duplicate at room temperature, 0 and −50° F. Table 2 shows a tubulation of the results.

Table 2—Keyhole Charpy Impact Results, in Ft-Lb

Testing temp.→	*Room temp.*	*0° F*	*−50° F*
Avg. location:			
No. 1	33.0	24.0	25.0
No. 2	33.0	28.0	22.5
No. 3	32.5	30.5	27.0
No. 4	39.0	30.0	27.0
No. 5	37.0	32.5	29.0
7/8-in. plate	23.0	4.5	2.5
1 1/32-in. plate	24.0	3.5	2.5

In order to secure additional information, we ran a similar set of tests using both a one-pass and a two-pass procedure of welding. By two passes is meant two beads of weld metal deposited on each side with both sides welded simultaneously. One pass, is one bead each side, both sides welded simultaneously. The test plates were 1- and 3/4-in., A283 Gr. C material. The specimens were taken midway from the center of the groove to the surface of the plate. One half was taken from the leading arc side and one half from the trailing arc side. All specimens were the keyhole Charpy type. Table 3 shows a tabulation of the results, all made at −50° F.

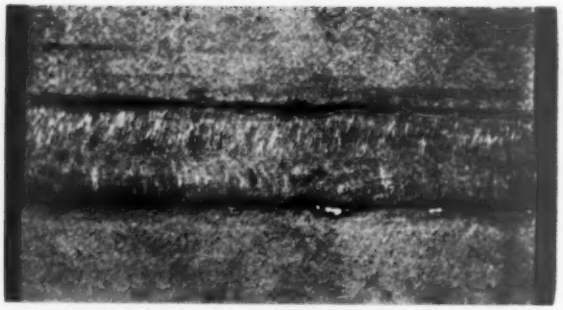

Fig. 21 Face view of automatically welded girth joint

Table 3—Keyhole Charpy Impact Results, in Ft-Lb Tested at −50° F

One-pass procedure		*Two-pass procedure*	
1H1	17.3	2H1	22.8
1H2	18.0	2H2	27.2
1H3	19.2	2H3	21.0
1H4	21.0	2H4	24.1
1H5	16.5	2H5	21.6
1H6	17.9	2H6	22.5
1H7	20.4	2H7	18.6
1H8	15.2	2H8	23.2
1-in. plate	2.5	1-in. plate	4.0
3/4-in. plate	4.8	3/4-in. plate	3.2

From the previously listed data it can be seen that the low-temperature impact properties of the weld metal are excellent. Additional physical characteristics of the submerged arc girth weld were checked by making tensile, free- and guided-bend and etch tests. Figure 14 shows some tensile specimens taken from a girth weld made between two A283 Gr. C plates, with the specimens machined to force the failure to occur in the weld metal. These two specimens failed at 72,500 and 74,000 psi. Many additional tensile tests were made and the results showed the ultimate strength to vary from 68,000 to 74,000 psi.

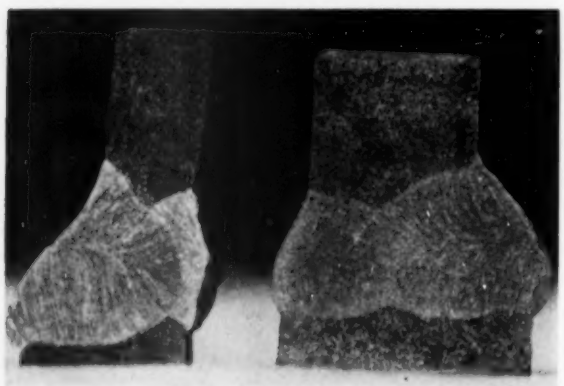

Fig. 20 Macro-specimens of automatically welded girth joints

Fig. 22 Erecting second ring of an 80,000-bbl tank

Fig. 23 Manually welding second-ring longitudinal joints and automatically welding first- to second-ring girth joints

Fig. 24 Manually welding third-ring longitudinal joints, automatically welding first- to second-ring girth joint and erecting third ring

Figure 15 shows four free-bend specimens made from a girth weld between two A283 Gr. C plates of $1^1/_8$ and 1 in. thickness. The elongations secured from these free bends varied from 32 to 44%. Figure 16 shows the face of the free-bend specimens. Note the soundness of the weld metal. Figure 17 shows four guided-bend specimens with one bent completely double following the 180-deg bend. Figure 18 shows the face view of these guided-bend specimens.

Many etched specimens were made to check the soundness of the weld metal. Figure 19 shows a macro-specimen of an automatic girth weld between $1^1/_4$ and $1^1/_{32}$ in. thickness plates. The weld was made with two passes each side. The density and quality of the weld are quite apparent. Figure 20 shows medium heavy and light plates welded together using the one pass procedure on each side. Note the contour of the welds, absence of undercutting and soundness of weld metal. Figure 21 shows the circumferential automatic weld. Note the absence of undercutting and the smoothness of the bead.

In all of the hundreds of specimens taken from both the laboratory and production work, cracking of the weld metal was very conspicuous by its absence. The reasons for this probably are the use of preheat, welding of both sides simultaneously, slow rate of cooling, low residual stresses and hydrogen-free weld metal. This comparative freedom from cracking again attests to the ductility of the weld metal.

The following views of the automatic girth welding machine in operation may be of some interest to you. Figure 22 shows the second ring of an 80,000-bbl tank being erected. Figure 23 shows the first to second ring joint being automatically welded while the vertical joints are being manually welded and the inside scaffolding is being raised to accommodate the hanging of the third ring. Figure 24 shows the first to second ring joint being completed, while at the same time the third ring is being erected and the third ring vertical joints are being welded manually. Figure 25 is a closeup view of the girth machine in operation. Note the preheating torch ahead of the welding tip and the red hot flux and plate just behind the tip.

Figure 26 shows the automatic in operation on the inside of a tank. A welding supervisor is checking the weld and the operation of the machine. Figure 27 shows a girth joint on the outside of a tank after welding and cleaning. Note the smoothness of the bead and the absence of banding. Figure 28 shows a completed tank after painting.

Much has been said concerning the development and the reasons why the automatic welding machine offers weldments of high quality to the purchaser of storage tanks. Little has been said concerning the difficulties that had to be overcome before the unit was perfected to the point where it demonstrated its value to the customer. Many tons of plate material were used in the

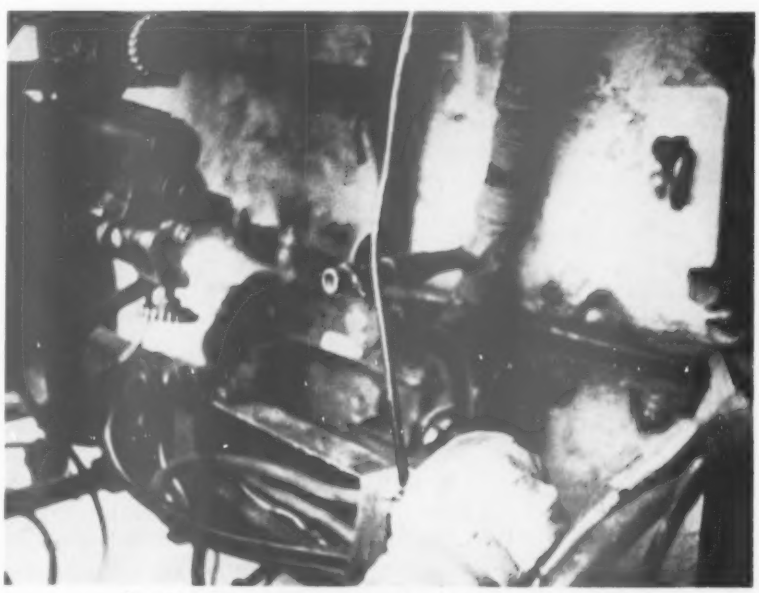

Fig. 25 Close-up view of girth machine in operation

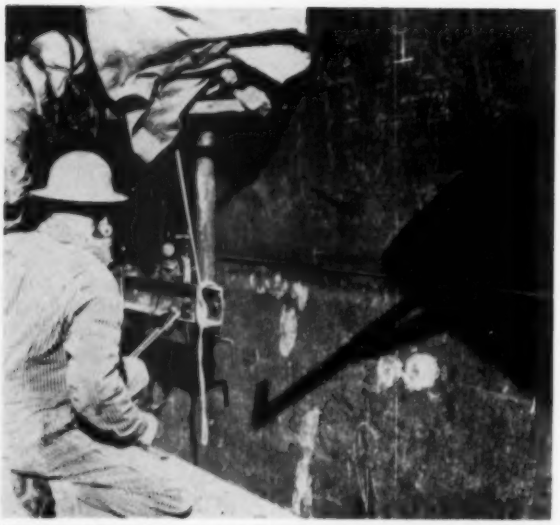

Fig. 26 Checking operations of an automatic girth welding machine

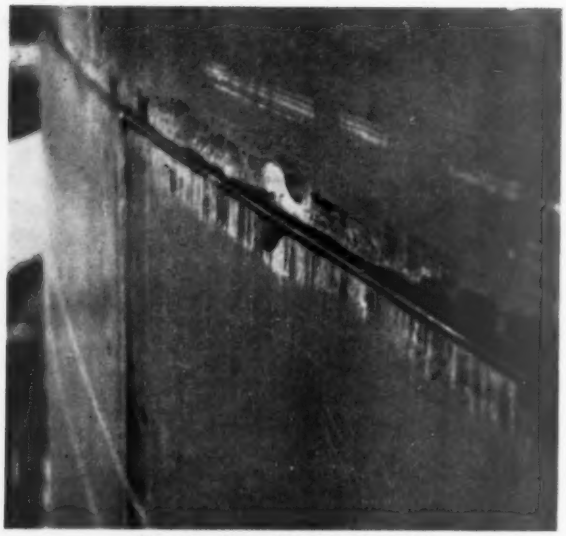

Fig. 27 Completed girth weld

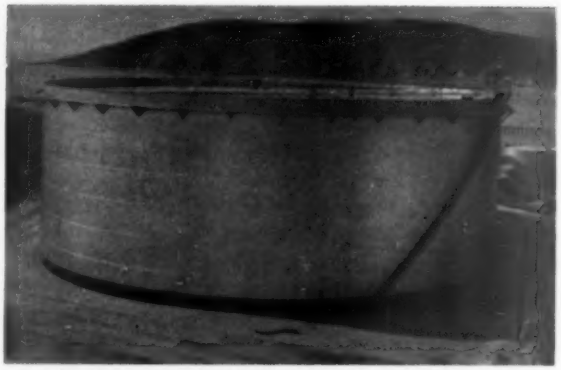

Fig. 28 Completed automatically welded tank

laboratory in making the weld tests. Much trouble was encountered with undercutting, slag entrapments and porosity before the right electrode, flux and welding data were secured. Hour upon hour was spent by many men in solving the complex problems. Successful operation came only after much effort was expended by the electrical, mechanical, metallurgical and welding engineers of the organization.

Following the long period of development and laboratory work came the huge task of training operators to run the mechanism. Fortunately, we had in our employ a great number of well-trained field welding supervisors. These specialists were shop trained to operate the automatic girth machine and then they, in turn, aided in the training of the field operators. They also acted as "trouble shooters" whenever serious trouble was encountered with any machine. Without the aid of these specialists, the task of our laboratory men attempting to field train the operators would have been impossible.

We wish to take this opportunity to publicly thank all of the people who have contributed in some degree to the development and application of the automatic girth welding machine. It was found necessary to have some special equipment made; the equipment manufacturers did their job well. Suggestions were made concerning the type of electrode and flux to be used. These were helpful. Even the purchasers of storage tanks contributed their part by allowing us to prove the value of our development on their vessels. The erection crews contributed their part by developing a new tank erection procedure which lent itself well to the use of the automatic.

Many thousands of tons of steel have been field welded into large tanks with the automatic girth welding machine. Tanks as small as 26 ft in diameter have been automatically welded as well as tanks as large as 330 ft in diameter. We feel that the use of this equipment has done much to improve the quality of the product furnished the purchaser. Much of the human element of error or misjudgment of hand welding has been eliminated since a machine will perform in the same manner from beginning to end of a joint once the operating or procedure data are correctly ascertained and used. However, a word of caution is provided to those who are considering the use of automatic equipment. Be sure your procedure is well tested and proved. This requires a tremendous amount of laboratory tests on large, representative test plates. It also requires the services of many talented men in the various fields of engineering. Assembling, operating and maintaining these machines is a large task in itself. Even the procedure of using the machine must be carefully planned. For instance, whenever a joint is started with an automatic welding machine, a weld sample or radiograph must be taken immediately to check the fusion and penetration secured.

The road has been paved, the ice broken, but unless the right road is chosen or the right channel used, the way may be full of detours and the sailing may be difficult and rough.

The Inert-Gas-Shielded Metal-Arc Welding Process

An Educational Lecture Series presented at the Annual Meeting of the American Welding Society on the Fundamentals of the Inert-Gas-Shielded Metal-Arc Welding Process

Part II

by W. H. Wooding

CHARACTERISTICS OF THE INERT-GAS-SHIELDED METAL ARC

As will be recalled prior to the development of this process, electric arc welding with bare wire electrodes was most difficult not only because of the questionable quality of the weld deposit but also because of the instability of the welding arc. The quality of the weld deposits was questionable because of the absorption of nitrogen and oxygen from the atmosphere. The instability of the welding arc resulted from the mode of metal transfer, which occurs in large globules, causing short circuits of relatively long duration.

Back in the late twenties, L. J. Weber of the University of Minnesota demonstrated that the quality of ferritic weld metal was greatly improved when deposited in a helium atmosphere. However, the welding arc was most difficult to maintain in the helium atmosphere. For this work it was reported that the welds were deposited with $^1/_8$-in. diam steel electrodes using a welding current of 100 to 150 amp on straight polarity; that is, the electrode was connected to the negative pole of a d-c source. These conditions paralleled those then in use for electric arc welding with bare-wire electrodes in air. Mr. Weber also reported improved arc action or arc stability when such welds were deposited in a carbon monoxide atmosphere.

However, the covered electrode at this time showed definite improved performance. Not only did it deposit good quality weld metal but the arc action or arc stability was greatly improved. The formulation of the coverings for these electrodes allowed wide latitude for the inclusion of arc stabilizing agents and arc stability continued to improve. In addition, other fluxing agents in the coverings could scavenge the impurities in the weld deposits caused by the presence of arc stabilizing agents.

Fig. 37 Inert-gas-shielded metal-arc

As has been pointed out, the inert-gas-shielded metal-arc welding process utilizes a bare-wire electrode. There are no arc stabilizing agents introduced into the process either through the shielding media or the wire. The shielding media is high-purity inert gas, either argon or helium or mixtures of both. The electrode wire which is to be discussed is 438 aluminum alloy and is considered free of gasses or other elements that might improve arc stability. Consequently, arc stability must be one of the functional characteristics of this process; and, it might be added the most important characteristic.

Operating on direct current with reverse polarity; that is, the electrode positive, the transfer of metal occurs in small droplets. The impressive characteristic of this inert-gas-shielded arc is that at some minimum current density which varies with both electrode

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size and material, metal transfer abruptly changes from large globules to a spray of fine droplets. At this current, the arc changes from a fluttering erratic discharge to a very steady quiet column. This minimum current density is far in excess of that used by early investigators of inert-gas-shielded metal-arc welding. In fact, it is also greatly in excess of that used for metal arc welding in general.

A photograph of the inert-gas-shielded metal arc is presented in Fig. 37. This arc is operating in an atmosphere of argon at a current density of approximately 75,000 amp per square inch of electrode cross section. The arc appears to consist of two regions: the outer plasma and the inner incandescent cone-shaped column. Of particular interest is the inner incandescent cone-shaped column. This column is well defined and quite steady. Through it, metal transfer takes place as a spray of fine droplets which are projected from the end of the electrode at a relatively high velocity. Also of interest is the cathode effect on the base plate. This is a d-c arc of reverse polarity which places the negative pole or cathode on the work. The sputtering which can be seen on the base plate about the periphery of the outer plasma of the arc is caused by the action of the cathode spot on the surface oxide on the metal. This action removes the oxides and cleans the work ahead of the arc preparatory to the deposition of the weld metal. This is particularly important in the welding of aluminum. Cleaned aluminum surfaces oxidize rapidly in air and if it were not for the cleaning action of the arc, the weld deposits would be quite porous because of this oxide despite efforts to clean the base metal by mechanical means prior to welding.

The stiffness of the inner column of this arc is readily demonstrated in Fig. 38. Here the gun has been tilted to an angle of approximately 30° with the work. It is to be noted that the inner column has assumed the same angle. Though the base of the column is somewhat wider and less defined than that shown in the previous photograph, metal transfer is still taking place through the column in a spray of fine droplets. Welding at this angle to the base material is not recommended.

Fig. 38 Inert-gas-shielded metal-arc, gun tilted 30 deg

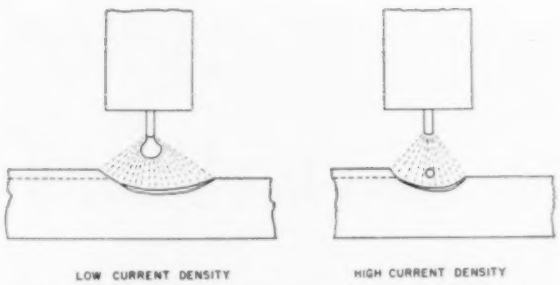


Fig. 39 Effect of current density on metal transfer

The effectiveness of the gas shield has been partially destroyed as indicated by the spatter of weld droplets around the puddle.

As previously stated, the process utilizes a high electrode current density to obtain satisfactory metal transfer. The influence of current density on metal transfer is illustrated in Fig. 39. The illustration on the left shows that with low current densities, large globules of molten metal form on the terminal end of the electrode and grow in size until by gravity they drop into the molten pool on the base metal. The erratic behavior of the arc during the period the globule is growing in size causes a very large crater to form in the work. This illustration portrays a current density somewhat higher than that used for metal arc welding in general. Consequently, short circuits when they occur are not of the long duration experienced with bare wire metal arc welding. The high current density illustration on the right shows a small drop of molten metal being projected from the end of the electrode terminal toward the center of the crater. It is to be noted that the crater is much smaller. For some electrode materials, a series of drops may be continually in transit across the arc but for aluminum, transfer generally takes place one drop at a time. Figure 40 presents photographs of the aluminum arc showing two stages of metal transfer. In the photograph on the left, the drop is forming on the end of the electrode and the one on the right shows the drop in transit across the arc. Note the apparent stiffness of the arc column and the size of the molten drop.

The actual effect of current density on metal transfer is shown in Fig. 41. This is a series of weld beads

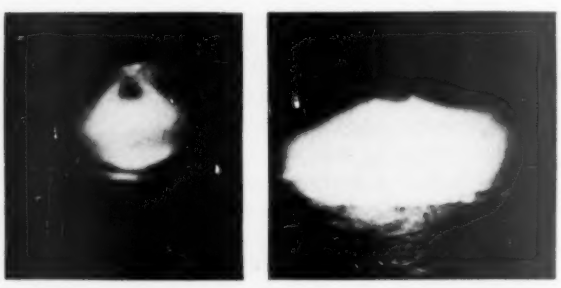


Fig. 40 Photograph—metal transfer in aluminum arc

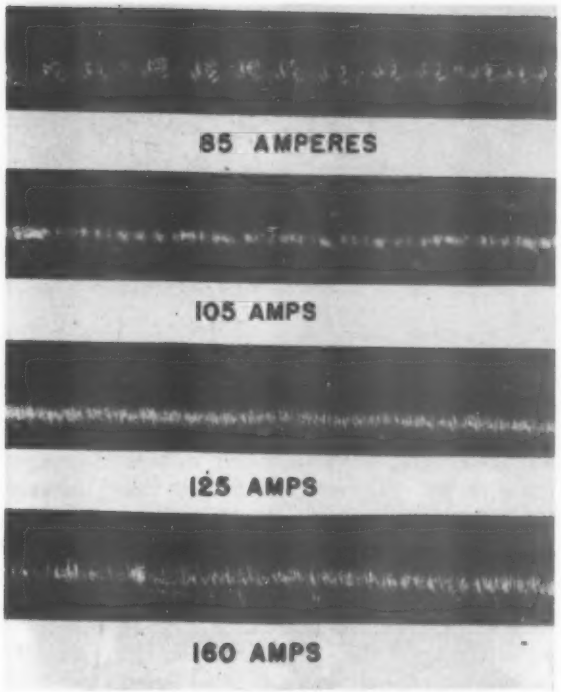


Fig. 41 Metal transfer versus current
Argon gas; 1/16-in. diam Al alloy 43S wire; 15 ipm arc travel speed.

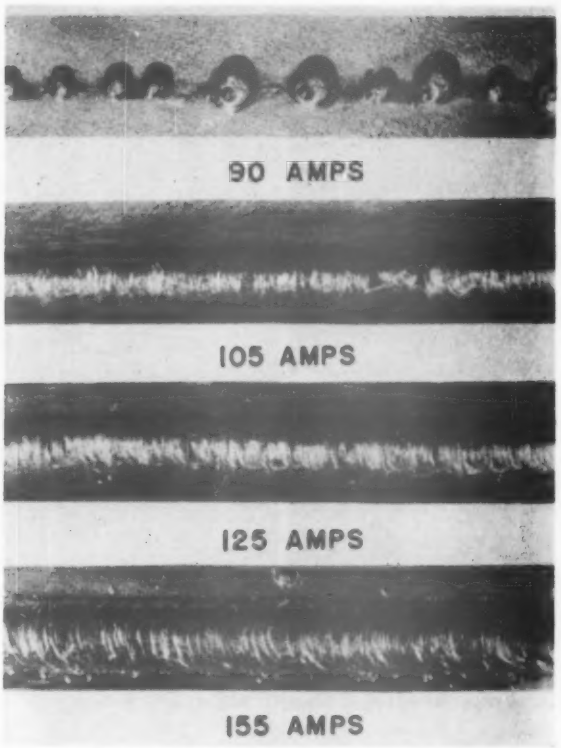


Fig. 42 Metal transfer versus current
Helium gas; 1/16-in. diam Al alloy 43S wire; 15 ipm arc travel speed.

deposited under similar conditions at various welding currents. All beads were deposited with 1/16-in. diam 43S aluminum alloy wire in an atmosphere of argon. Of course it was necessary to increase the wire feed to accommodate the higher welding currents so that the proper arc voltage could be maintained. At 85 amp, a current density of approximately 27,000 amp per square inch, the arc is very unstable and all that can be deposited are large discontinuous globs of weld metal. With the deposition of each glob, the arc is extinguished and must be restarted. At 105 amp, approximately 34,000 amp per square inch, the globs are somewhat smaller and almost continuous but the arc is still unstable. Around 125 amp, approximately 40,000 amp per square inch, the arc is fairly stable and a continuous bead can be deposited. At 160 amp approximately 52,000 amp per square inch, the arc is quite stable and a very uniform bead is deposited. In comparison, for general metal arc welding, electrodes operate at a current density of approximately 7000 amps per square inch; about one-sixth the current density required for the inert-gas-shielded metal arc. Though the ionization potential for helium is somewhat higher than that for argon, the effect of current density is the same and as indicated in Fig. 42, 125 amp or a current density of approximately 40,000 amp per square inch is required for minimum arc stability. What these photographs do not show is that with increase in current density the size of the molten droplet decreases. However, the data do establish the fact that to use this process effectively a high current density is required and for general applications it will approximate 40,000 to 70,000 amp per square inch of electrode cross section. In this range of current density the metal transfer occurs in a spray of finely divided particles ejected in an orderly fashion at high velocity from the electrode. No effort has been made to determine the maximum current, for though there appears to be a limit, undercutting and poor weld contour will occur prior to reaching that limit.

Fig. 43 High-speed photograph—metal transfer in overhead position

Using high current densities, welding in any position is readily accomplished with this process. Figure 43 is a series of reproductions from a high-speed motion picture study of an aluminum weld being deposited in the overhead position. The top photo shows the drop of molten metal which has formed at the tip of the electrode. It is necking down as though being pinched from the electrode. The second photo shows the

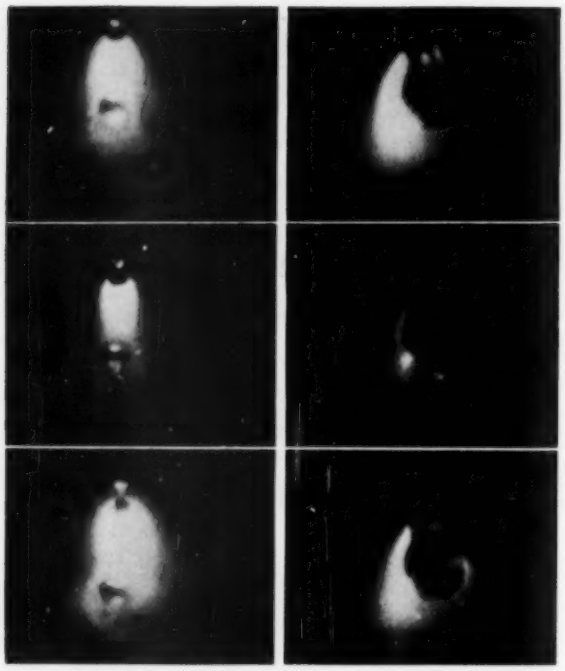


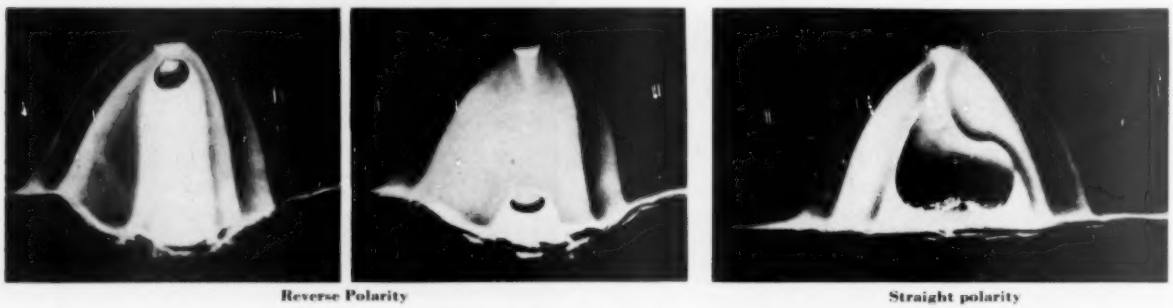
Fig. 44 High-speed photograph—comparison of metal transfer between straight and reverse polarity

drop in transit and the third photo shows the drop landing in the molten pool. This action takes place in a very small part of a second. Since the electrode metal is relatively free of gas, metal transfer is not considered to be accomplished by the expansion of gases at the electrode tip, the generally accepted theory of metal transfer for covered electrodes. From these photos, it would appear that the electrical forces are pinching the drop from the tip of the electrode and propelling it across the arc. In view of the high current densities used with this process and the fact that metal transfer occurs in small droplets, it is believed that the electrical forces developed in the arc are sufficient to pinch off the small droplets of molten metal from the electrode and propel them at high velocity into the weld pool.

So far, the discussion has been concerned with the operation of the equipment on d-c reverse polarity; that is, the electrode positive. When the equipment is operated on d-c straight polarity (electrode negative)

Fig. 45 High-speed photograph—straight polarity metal transfer

a somewhat different arc action is observed. A series of reproductions from a high-speed motion picture study of reverse and straight polarity arcs is presented in Fig. 44. The arc series on the left is the reverse polarity arc and shows an orderly transfer of droplets across the arc. The series on the right shows the same arc on straight polarity. Here the molten metal forms in large globules and seems to have no initiative to drop from the tip of the electrode. A better photograph of the straight polarity arc is shown in Fig. 45. Here a large globule of molten metal can be seen growing at the tip of the electrode. From the position of the drop, it appears that it is being forced away from the plate. In fact one droplet is in flight as if propelled from the arc beyond the inert-gas shield. Figure 46 presents several sketches showing the typical characteristics of reverse and straight polarity arcs. The reverse polarity arc follows the characteristics which have been previously discussed. Small droplets which form at the tip of the electrode are pinched off and propelled across the arc to the weld pool. However, with straight polarity, a large droplet of molten metal forms at the tip of the electrode. The drop shown here is being pulled away from the electrode by the force of gravity. However, the repulsive effect of the anode on the work is holding the drop away from the weld pool. Note the cathode sputtering on the underside of the globule and the lack of such sputtering on the base plate such as occurred with reverse polarity. This study indicates that on straight polarity the arc loses its stability and assumes the characteristics of a very low current density arc on reverse polarity. Since alternating current is a constant reversal of polarity, the characteristics of the a-c arc will alternate between those of the straight polarity arc and those of the reverse polarity arc.



Reverse Polarity

Straight polarity

Fig. 46 Inert-gas-shielded metal-arc process, direct current

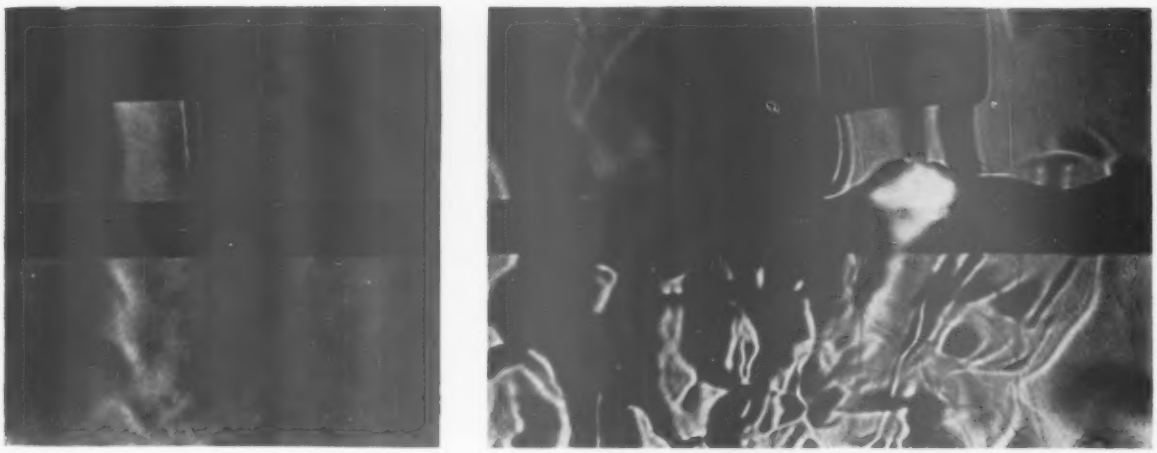


Fig. 47 Schlieren picture of argon gas shield

Such conditions would cause an alternating stable and unstable arc which would be objectionable without the use of some arc stabilizer to improve straight polarity operation.

Having established the electrical conditions for a stable arc (high current density with d-c reverse polarity), the next problem is to determine the minimum gas flow for satisfactory shielding of the arc stream and molten weld metal. The pattern of an argon gas envelope as it flows from the gun is shown in the Schlieren pictures presented in Fig. 47. The Schlieren picture on the left shows the gas pattern without the distortion that is caused by the welding arc. The gas flows from the nozzle in a stream which completely surrounds the electrode wire. It flows over a small metal tube which has been inserted to represent the work. The flow of gas from the gun to the surface of the tube is free of turbulence. The picture on the right shows the effect of the arc on the gas flow pattern. Here again attention is invited to the flow of gas from the gun to the surface of the tube representing the work. This flow, though somewhat distorted by the arc, is relatively free of turbulence and on reaching the surface of the tube spreads out to blanket areas somewhat removed from the arc. However, below the tube there is considerable turbulence probably caused by the heat from the arc but this heat appears to have no effect on the gas blanketing the arc.

A comparison between the shielding effect of argon and that of helium is shown by the Schlieren photographs presented in Fig. 48. In these photographs, a tungsten arc was established on a flat surface to simulate the deposition of a butt or bead weld. The argon gas on leaving the nozzle appears to hug the surface of the work and blankets a considerable area. The helium has a tendency to rise from the work after coming in contact with the surface. This is to be expected in view of the density of helium which is lighter than air. Though the blanketing effect is not as extensive as that obtained with argon, helium does cover the surface for a considerable distance beyond the arc. However, by increasing the velocity of the gas coming from the nozzle, the blanketing effect is increased. In any event, argon being the heavier of the two gases (40.4) should provide effective blanketing at lower velocities.

These Schlieren pictures were made with the welding gun stationary. In moving the gun, as would be encountered in welding, the coverage pattern becomes somewhat distorted. Figure 49 schematically portrays the effect of the speed at which the gun is moved on the

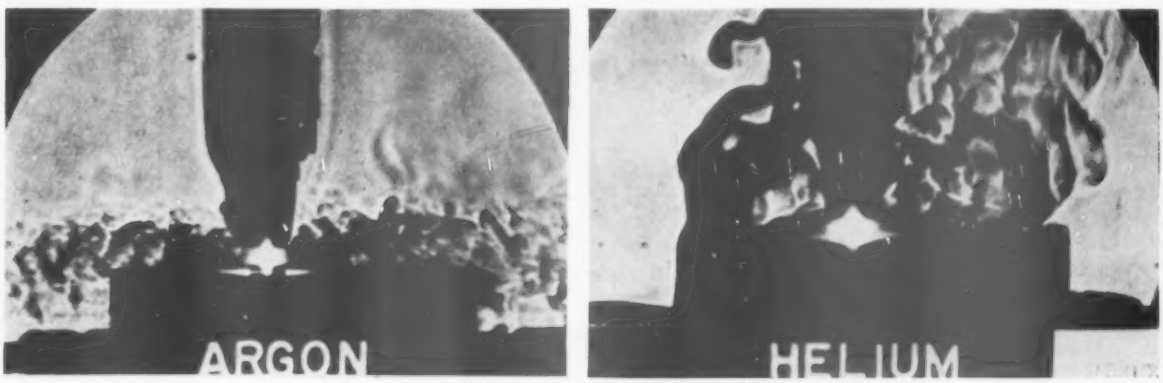


Fig. 48 Schlieren pictures—argon as compared to helium gas shields

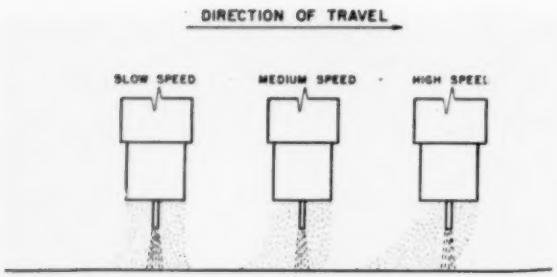


Fig. 49 Effect of welding speed on gas shield (constant gas flow and welding current)

coverage of the gas shield. When moved at very slow speeds, the gas pattern is quite similar to that shown in the Schlieren pictures. With the gas flow held constant, any increase in the speed of travel of the welding gun causes the gas pattern to be pulled back to the retreating side of the gun by the drag of air surrounding the gas envelope. If the speed becomes too great, the gas shield may be pulled back to the extent that the terminal end of the arc on the work is exposed. Consequently, gas flow should not only be adequate to shield the arc but must also be of sufficient velocity to overcome the drag of air caused by the speed of welding.

Figure 50 is a series of photographs of weld beads deposited using several gas flows at various arc travel speeds. These beads were deposited with $^{3}/_{32}$-in. diam 43S aluminum alloy wire at 200 amp using helium for the gas shield. At an arc travel speed of 12 ipm and a gas flow of 50 cfh, much of the deposit consists of nothing but weld spatter, indicating ineffective gas shielding. At 100 and 150 cfh, the beads have good appearance indicating adequate coverage. At 25 ipm arc travel speed, the bead deposited with 100 cfh gas flow has very poor appearance again indicating ineffectual gas shielding. With 150 cfh, there is considerable spatter but the bead does have fair surface appearance. The bead deposited with 200 cfh indicates that gas flow to give more effectual coverage than the lower gas flows. However, at an arc travel speed of 50 ipm a gas flow of 200 cfh is not fully effective in providing adequate shielding.

This same effect also applies to argon gas as illustrated in Fig. 51. It is to be noted that the gas flows are somewhat lower for argon than they were for helium which is primarily due to its greater density or weight. At 12 ipm arc travel speed, fully effective gas coverage is not obtained until the gas flow approaches 50 cfh. At 25 ipm, the gas flow is not fully effective until it approaches 80 cfh.

To further determine the effectiveness of various gas flows in providing adequate protection in various welding positions, butt welds were deposited in the overhead position under several conditions of gas flow and

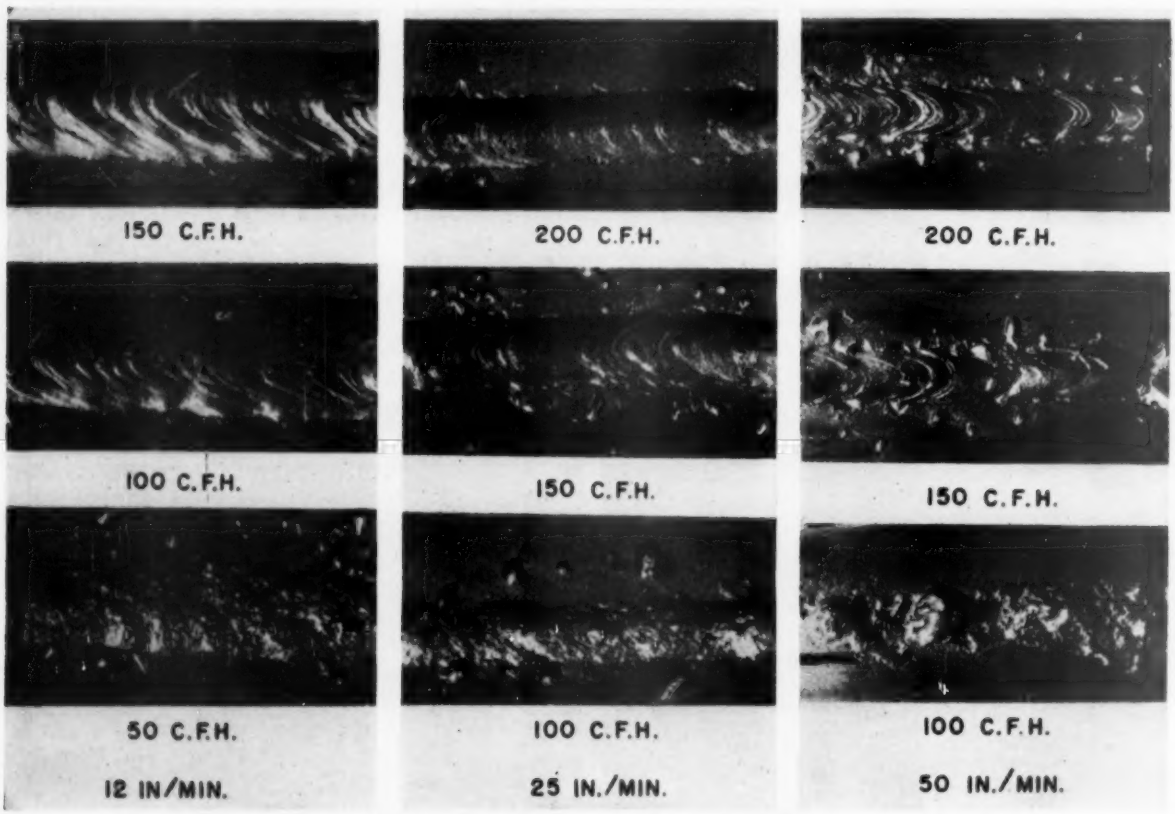


Fig. 50 Arc travel speed

Helium gas; $^{3}/_{32}$-in. diam Al alloy 43S wire; 200 amps; 28 arc volts.

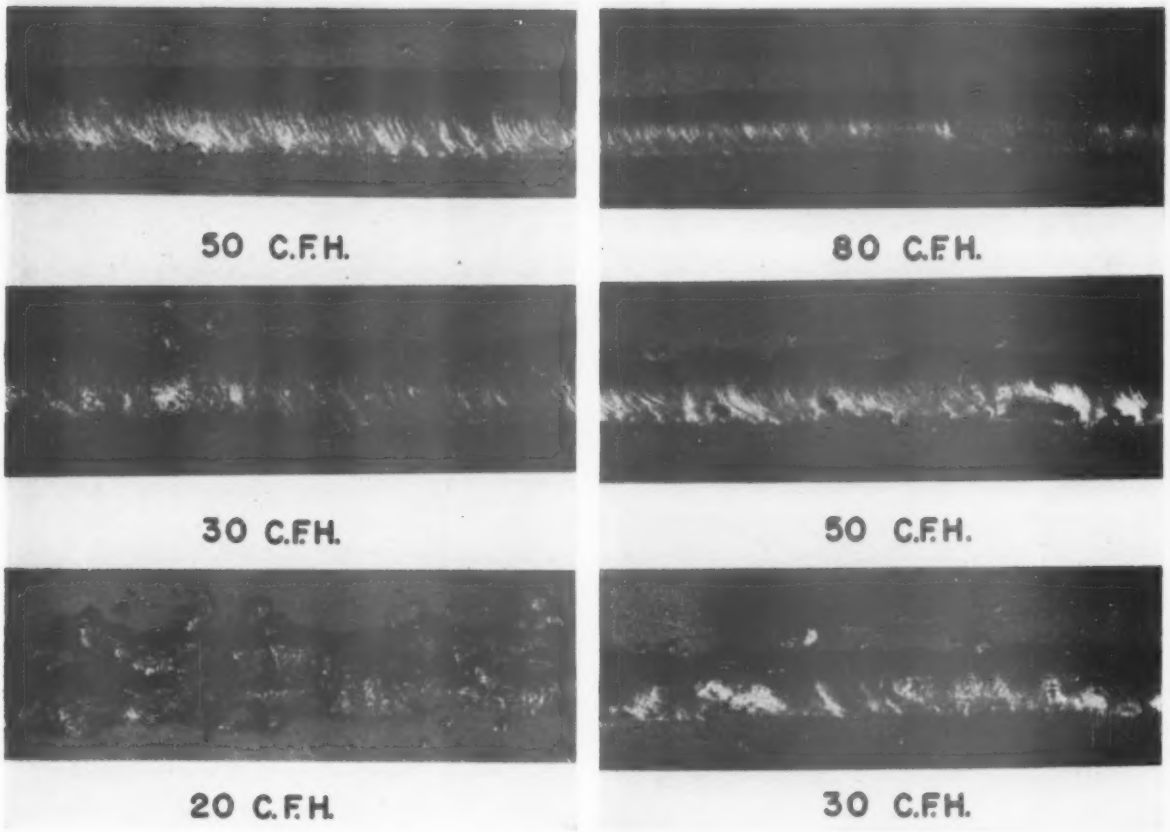


Fig. 51 Arc travel speed

Argon gas; 1/8-in. diam Al alloy 43S wire; 220 amp; 23 arc volts.

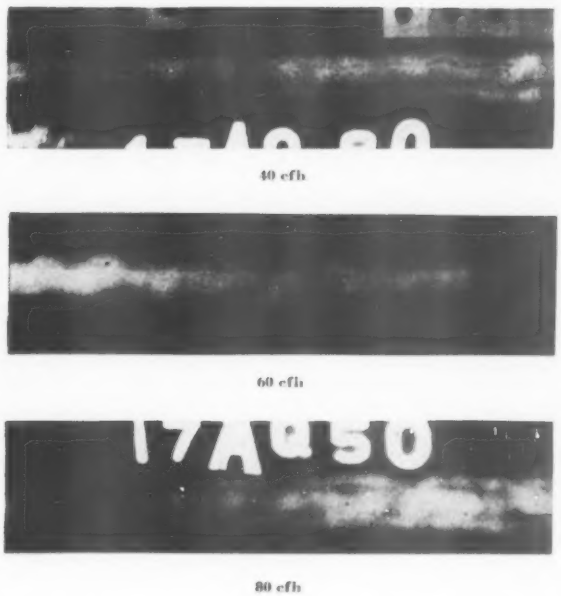


Fig. 52 Effect of argon gas flow on porosity of welds

Argon gas; 1/2-in. diam nozzle; 180 amp; 23 arc volts; overhead position; 1/16-in. diam "C" finish wire.

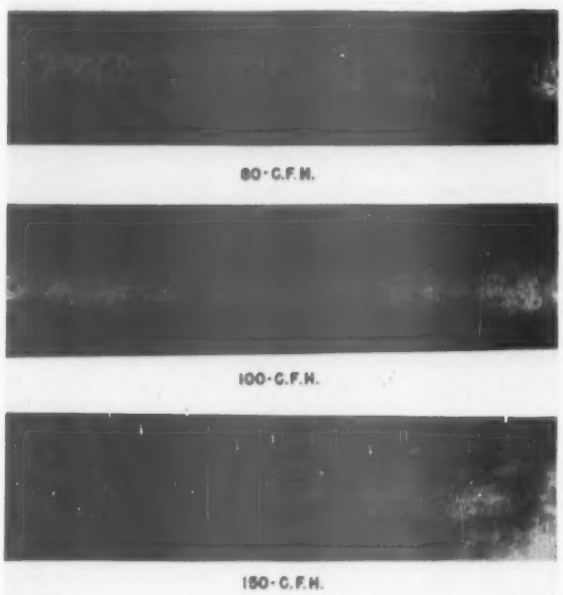


Fig. 53 Effect of helium gas flow on porosity of weld metal

Helium gas; 1/2-in. diam nozzle; 160 amp; 30 arc volts; overhead position; 1/16-in. diam "C" finish wire.

examined by X-ray. All welds were deposited under the same conditions of welding at an arc travel speed of approximately 12 ipm. Figure 52 shows reproductions of X-ographs of butt welds deposited using various flows of argon. At 40 cfh, the weld has considerable porosity which substantiates the findings of the bead test which was just discussed. At 60 cfh, the effectiveness of the gas shield is considerably improved but there is still some porosity present. At 80 cfh, the gas flow is fully effective in providing adequate coverage. The butt weld is free of porosity.

Figure 53 presents a similar series of reproduced X-ographs of butt welds made at several flows of helium gas. Porosity in the butt welds deposited using 80 and 100 cfh of helium indicates that the shielding is not fully effective. At 150 cfh, the butt weld is free of porosity indicating that this flow of gas gives adequate shielding.

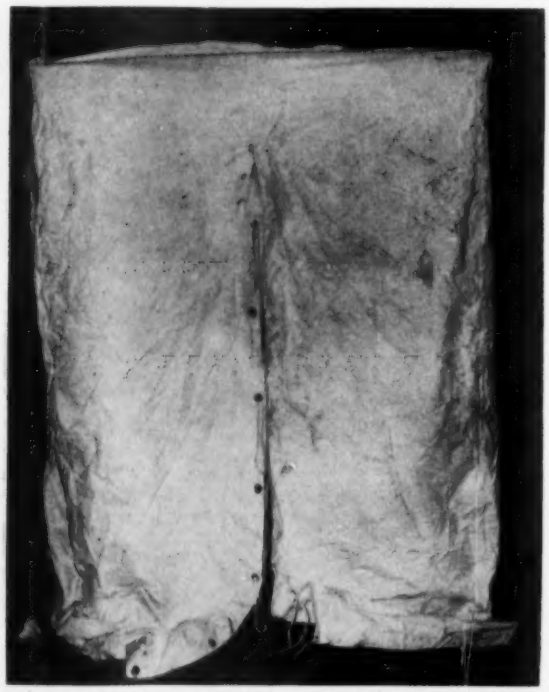


Fig. 54 Canvas shield for out-of-doors welding

The results of this study should not be minimized. The required gas flow to provide adequate shielding not only depends on the welding technique but also upon the conditions surrounding the welding operation. The influence of the speed of welding on the effectiveness of the gas shield also indicates the difficulties that may be caused by drafts or wind. For welding in the open or out-of-doors, a canvas enclosure such as that shown in Fig. 54 should be used to protect the process. A second view of this enclosure with the canvas partly withdrawn to show the operator is shown in Fig. 55. The enclosure need not be elaborate so long as it acts as an effective windbreak. However, the area should not be totally enclosed otherwise there would be insufficient ventilation for removal of welding fumes.

Fig. 55 Use of canvas shield to protect process

Thus far, it has been demonstrated that argon and helium may be used interchangeably with the inert-gas-shielded metal-arc welding process. However, approximately twice the flow of helium is required to obtain effective shielding comparable to that of argon. Since these two gases are different in weight and ionization potential, they do produce individual arcs of different characteristics. At a normal arc voltage of from 22 to 24 v, the argon-shielded arc has a low steady buzzing sound while the helium-shielded arc has a harsh, sharp, crackling sound. Even at 30 arc volts, the helium-shielded arc is quite noisy; and, as one operator put it, it sounds like eggs frying on a hot skillet. This noise does not appear to be indicative of instability of the arc but seems to be associated with other characteristics of the welding arc.

There is a noticeable difference in the mechanical arc length of argon-and helium-shielded arcs operating over the same range of arc voltage. Figure 56 presents a series of curves showing the changes in visible mechanical arc length with change in arc voltage for argon- and helium-shielded arcs operating at a welding current of 180 amp. As shown, the change in arc length for unit change in arc voltage is much greater for the argon-shielded arc when compared with that of the helium-shielded arc. Argon arcs operating at an arc voltage of 18 v are quite noisy and do not quiet down until the arc voltage reaches 22 v. To obtain the same visible mechanical arc length with helium

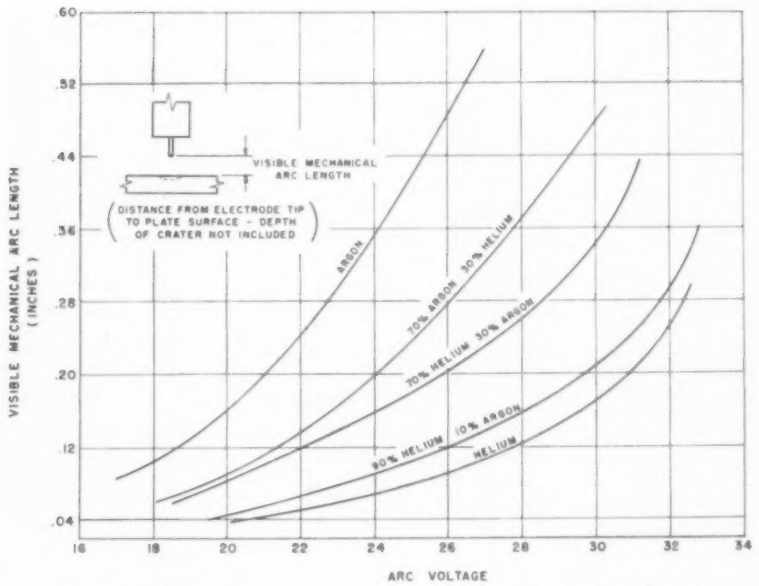
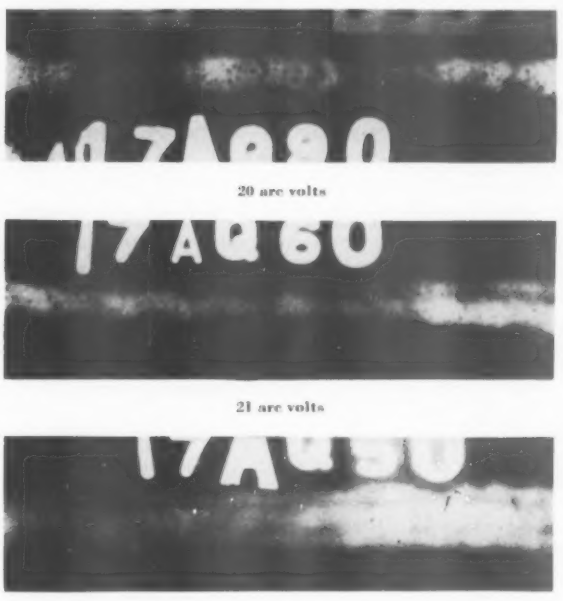


Fig. 56 Relationship of arc voltage to visible mechanical arc length

requires an arc voltage of approximately 32 v. Surprising enough, at an arc voltage of 32 v, the helium-shielded arc begins to quiet down. The other curves presented show the effect of mixing argon with helium to improve the arc characteristics. As would be expected, as the argon is increased, the arc length characteristics tend to approach those of the pure argon shield.

The effect of arc voltage also was investigated by depositing butt welds at various arc voltages for both argon- and helium-shielded arcs. Figure 57 presents the series of X-ographs of butt welds deposited using argon for the shielding medium. At 20 arc volts the weld is quite porous. When the voltage was increased to 21, the porosity was considerably reduced. At 23 arc volts, the weld appears to be free of porosity. A similar series showing the effect of arc voltage on the helium-shielded arc is presented in Fig. 58. At 24 v, the weld is quite porous. Increasing the arc voltage to 28 v greatly reduces the amount of porosity. However, at 30 and 32 arc volts, the welds appear to be free of porosity. Thus it would appear that the arc voltage or mechanical arc length not only affect the audible characteristics of the arc but also the quality of the weld deposits. Furthermore, it would appear that there is a minimum mechanical arc length common to satisfactory operation in argon or helium.

Another interesting difference between the two gases is their effect on the burn-off rate or the rate at which electrode wire is consumed. Figure 59 presents the burn-off rates over a range of welding current for each of the two gases. As indicated, the burn-off rate is a



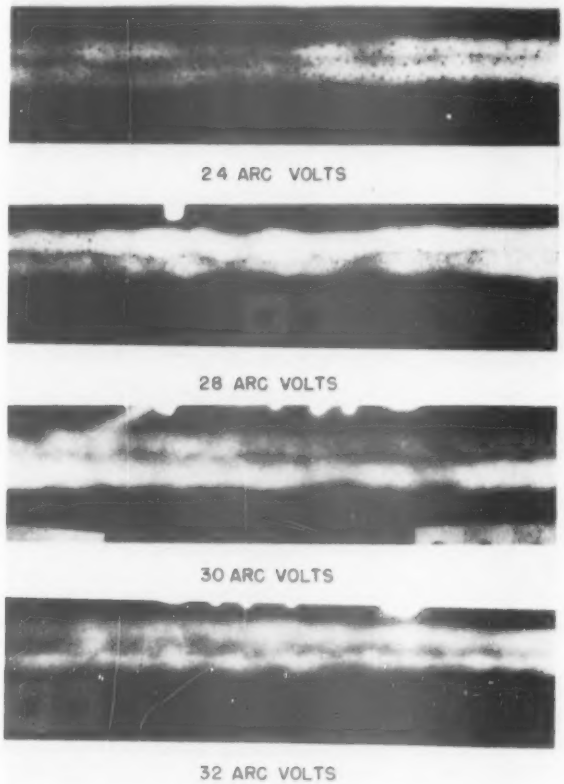
20 arc volts

21 arc volts

23 arc volts

Fig. 57 Effect of arc voltage on porosity of weld deposits using argon

Argon gas; 80 cfh; 1/2-in. diam nozzle; 1/16-in. diam "C" finish wire.



24 ARC VOLTS

28 ARC VOLTS

30 ARC VOLTS

32 ARC VOLTS

Fig. 58 Effect of arc voltage on porosity of weld deposited using helium

Helium gas; 150 cfh; 1/2-in. diam nozzle; 1/16-in. diam "C" finish wire.

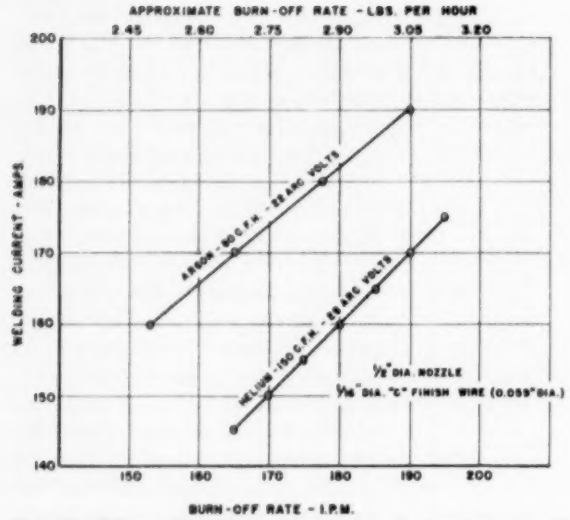


Fig. 59 Effect of welding current on electrode burn-off rate

function of the welding current and increases with increase in current. However, the burn-off rate in the helium atmosphere is somewhat higher than it is in an argon atmosphere for the same welding current. Attention is invited to the fact that the burn-off rates in the helium atmosphere were determined at 28 arc volts while those for the argon atmosphere were determined at 22 arc volts.

Further investigation indicated that arc voltage also influenced the burn-off rate. As shown in Fig. 60 the burn-off rates for a constant welding current vary inversely with the arc voltage in either atmosphere.

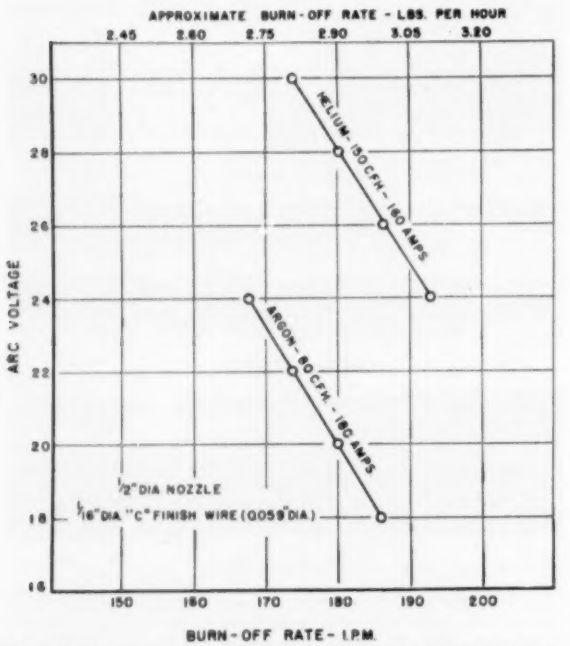


Fig. 60 Effect of arc voltage on electrode burn-off rate

In an argon atmosphere the burn-off rate varies from 165 to 185 ipm over an arc voltage range of from 24 to 18 v. While in a helium atmosphere the burn-off rate varies from 175 to 195 ipm over an arc voltage range of from 30 to 24 v. This apparent effect of arc voltage on the burn-off rate is considered to be actually caused by the radiant energy reflected from the cathode spot. The effect of such reflected heat would vary inversely as the square of the distance from the cathode spot to the terminal end of the electrode and, as a result, its influence on the burn-off rate would vary with arc voltage. Since the mechanical arc length in a helium atmosphere is generally shorter it is to be expected that with this effect higher burn-off rates would be obtained in helium atmospheres when compared with those obtained in argon.

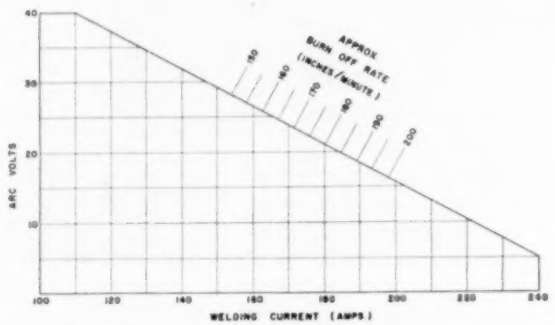


Fig. 61 Relationship of arc voltage and current with burn-off rate (observed values in argon atmosphere) (4043S aluminum alloy wire, 1/16 in. diam)

The influence of arc voltage and current on the burn-off rate of the electrode wire in combination with positive wire feed provides an automatic arc regulation characteristic unknown to other welding processes. Using an idealized d-c welding generator volt-amperage characteristic curve as presented in Fig. 61, it is to be noted that for every change in voltage, there is a change in current. Plotting the burn-off rate on the volt-ampere curve, we have a wide range of burn-off rates for a rather restricted range of volt-ampere characteristics. So long as the wire feed is held constant, any change in the electrical conditions resulting from either the power source or change in mechanical length, the burn-off rate immediately increases or decreases bringing the welding conditions back to those previously determined by the operator. This feature makes the process automatic and it is possible to set up the semiautomatic equipment for automatic operation by merely providing for the movement of the work under the arc. As shown in Fig. 62 a circumferential butt weld joining two tubes together is being deposited in an automatic fashion using the semiautomatic equipment. The tubes are on rollers so that they rotate and welding is performed by permanently locating the welding gun at a fixed distance above the surface to be welded. Once started, the operation is continued until the butt weld is completed.

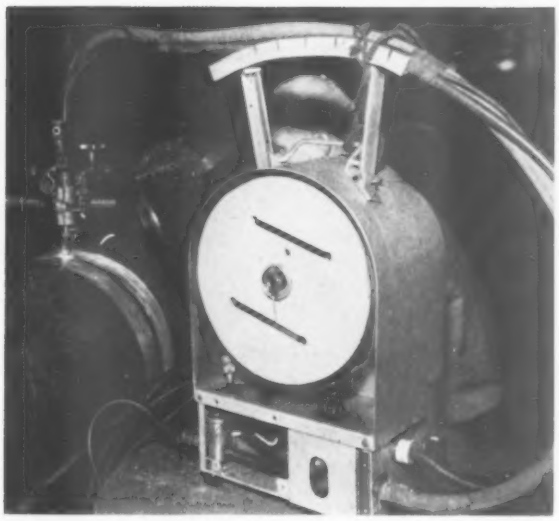


Fig. 62 Manual gun set up for automatic operation

There is one difference between the characteristics of the argon- and helium-shielded arcs which may dictate preference for either of the two gases. Weld penetration; that is, the depth the weld metal penetrates the work, is readily controlled by the selective use of either gas. Figure 63 shows the depth of penetration as a function of the welding current for each of the two gases. The argon-shielded arc shows much less penetration for the same welding current when compared with helium. This feature is important, since by nature, the process demands high current densities and should it be necessary to keep penetration to a minimum, it is more easily accomplished using argon. If, on the other hand, maximum penetration is desired, helium should be used. However, helium does permit higher welding speeds and shallow penetration can be obtained with helium by increasing the rate of arc travel speed. As shown in Fig. 64, travel speeds of 60 to 80 ipm are possible using helium and at such speeds the depth of penetration is greatly reduced. At welding speeds in excess of 50 ipm, argon has not been found very satisfactory.

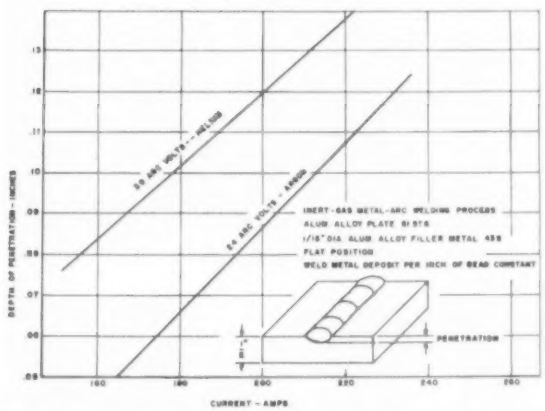

DEPTH OF PENETRATION - INCHES
CURRENT - AMPS
INERT-GAS METAL-ARC WELDING PROCESS
ALUM. ALLOY PLATE 61-ST-6
1/16" DIA. ALUM. ALLOY FILLER METAL 43S
FLAT POSITION
WELD METAL DEPOSIT PER INCH OF BEAD CONSTANT
PENETRATION

Fig. 63 Comparative effect of argon and helium shield on penetration

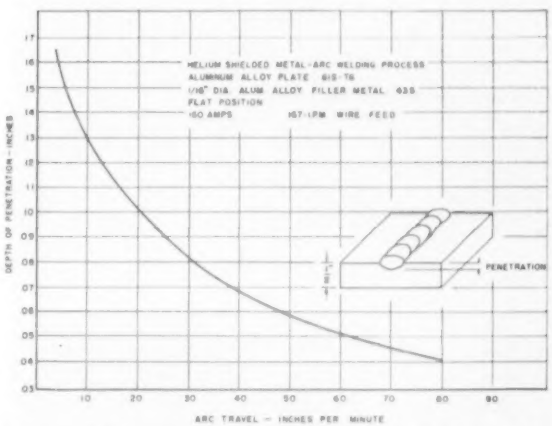

HELIUM SHIELDED METAL-ARC WELDING PROCESS
ALUMINUM ALLOY PLATE 61S-T6
1/16" DIA. ALUM. ALLOY FILLER METAL 43S
FLAT POSITION
150 AMPS
187 I.P.M. WIRE FEED
DEPTH OF PENETRATION - INCHES
ARC TRAVEL - INCHES PER MINUTE
PENETRATION

Fig. 64 Effect of arc travel speed on depth of penetration

ALLOY TYPE		CHEMICAL COMPOSITION %													
		C	Mn	Si	S	P	Ni	Cr	Mo	Ti	Pb	Sn	Al	Cu	Fe
STAINLESS STEEL	WIRE	.079	1.43	.58	.016	.019	10.52	18.58	--	.95	--	--	--	--	--
TYPE 321	WELD	.085	1.44	.63	.012	.016	10.52	18.78	--	.85	--	--	--	--	--
STEEL	WIRE	.13	1.13	.16	.016	.022	--	--	.18	--	--	--	--	--	--
1% Mn	WELD	.09	1.07	.18	.017	.023	--	--	.19	--	--	--	--	--	--
ALUMINUM	WIRE	--	.02	4.57	--	--	--	--	--	--	--	--	95.37	.05	.40
43S	WELD	--	.03	4.45	--	--	--	--	--	--	--	--	95.35	.10	.43
NICKEL	WIRE	.04	--	.59	.005	--	95.08	--	--	2.32	--	--	.90	--	.57
No. 61	WELD	.04	--	.62	.005	--	95.24	--	--	2.36	--	--	.96	--	.63
PHOS. BRONZE	WIRE	--	--	--	--	--	--	--	--	--	3.66	5.24	--	BAL.	.05
LEADED	WELD	--	--	--	--	--	--	--	--	--	3.57	4.97	--	BAL.	.04

Fig. 65 Semiautomatic inert-gas metal-arc welding process

Chemical composition of filler wire and deposited metal

The effectiveness of the inert-gas-shielded metal arc is indicated by the efficient transfer of metal from the electrode to the deposit. In this process, electrode wires are used which have the same composition as that desired in the weld deposit. The efficiency with which these alloys are transferred across the arc is shown in Fig. 65. As shown, stainless steel, low-alloy ferritic steel, aluminum alloys, nickel alloys and leaded phosphorus bronze are readily transferred across the arc without appreciable loss of any of the alloying elements. Even an active element like titanium is recovered in surprisingly high percentages. However, metals like zinc which have a very low vaporizing temperature are not readily transferred across the arc without excessive loss.

APPLICATION

The inert-gas-shielded metal-arc welding process was originally introduced to industry as a rapid method for the fusion welding of aluminum and aluminum alloys. Limited application soon established the suitability of the process for this purpose. The resulting demand for its use in aluminum fabrication fostered rapid strides toward improving the quality of the weld metal deposited by the process. Within a short period of time, factors responsible for the porosity in the weld metal were established and the means for their elimination quickly adopted. These included improvement in equipment design, cleanliness of the surface of the core wire, purity of the shielding gases, adequacy of gas flow and proper welding techniques. The effect of these various factors and their elimination have been previously discussed. With these improvements, the process readily demonstrated its ability to deposit good quality weld metal meeting the most stringent code requirements.

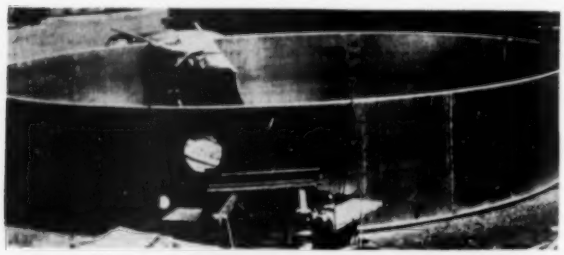


Fig. 66 Aluminum formaldehyde storage tank

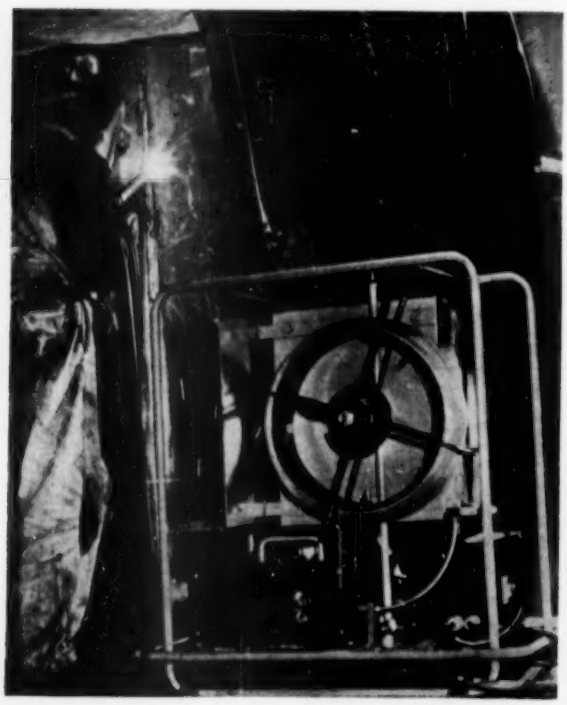


Fig. 67 Showing use of canvas shield to protect the process

A large variety of aluminum structures has been fabricated using the inert-gas-shielded metal-arc welding process. These include various types of containers or vessels, many of which are used by the chemical industry. Figure 66 is a photograph of a large formaldehyde storage tank during construction. This tank,

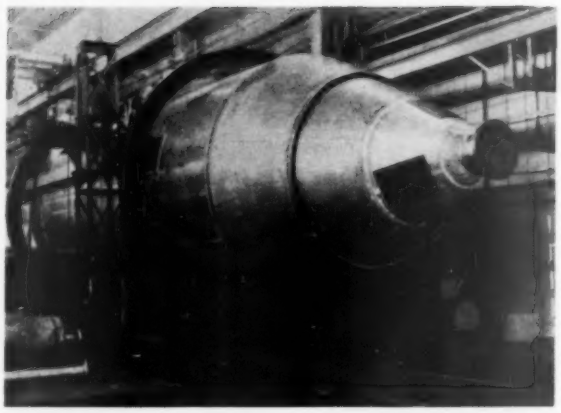


Fig. 68 Completed aluminum processing tank

Fig. 69 Completed sump tank body

35 ft in diameter, was constructed with 2S aluminum plate material 1 in. thick and was partly fabricated using the inert-gas-shielded metal-arc welding process. Since this was outdoor work, the operator on the far side of the tank is hidden from view by the canvas enclosure erected for the protection of the process. A close-up of the enclosure with the canvas drawn back to reveal the operator is shown in Fig. 67. The fillet wire used was $^1/_{16}$-in. diam 2S aluminum wire.

A photograph of a welded aluminum processing tank is shown in Fig. 68. This tank is 11 ft in diameter and 35 ft long. It is composed of 2S aluminum plates $^1/_2$, $^3/_8$ and $^5/_{16}$ in. thick and was fabricated for the most part using the inert-gas-shielded metal-arc welding process. Again $^1/_{16}$-in. diam 2S aluminum filler wire was used for depositing welds by this process.

An all-aluminum oil sump tank body is shown in Fig. 69. The fabrication of this tank requires 120 ft of welding. Using the inert-gas-shielded metal-arc welding process, this is accomplished in two man-hours. The welds deposited at this speed are of excellent quality.

The construction field has found wide application of the process in the fabrication of lightweight structures. Figure 70 shows an operator fabricating an aluminum alloy truss to be used in the construction of portable plane hangars. This truss is composed of 61ST6 aluminum alloy and is being fabricated by the inert-gas-shielded metal-arc welding process using 43S aluminum alloy filler wire. A photograph of completed truss sections is presented in Fig. 71.

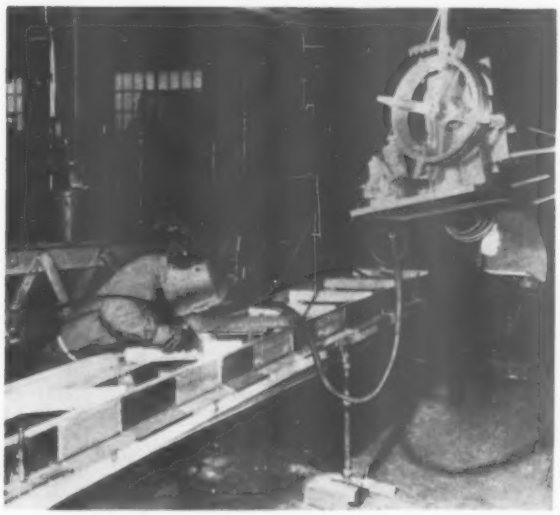


Fig. 70 Fabrication of aluminum truss section

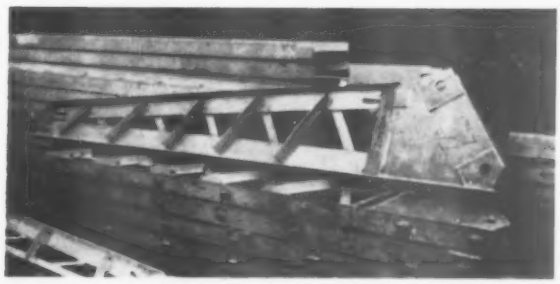


Fig. 71 Completed truss sections

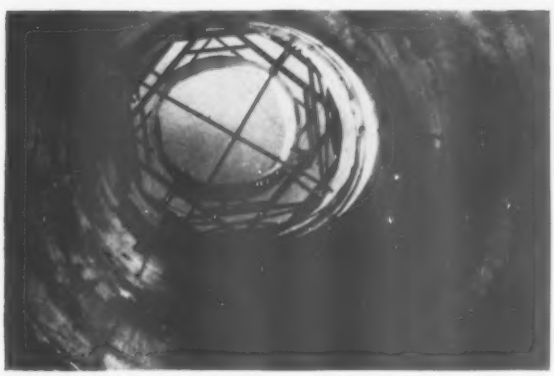


Fig. 72 Ammonium nitrate prilling tower

Fig. 73 Operator depositing vertical weld

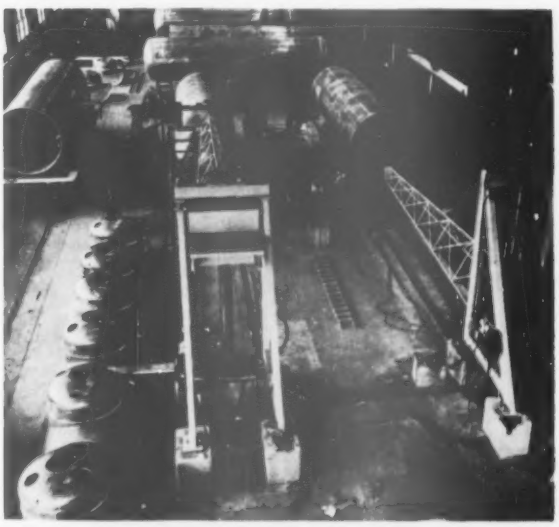


Fig. 74 Fabrication of aluminum tank cars for transportation of acids

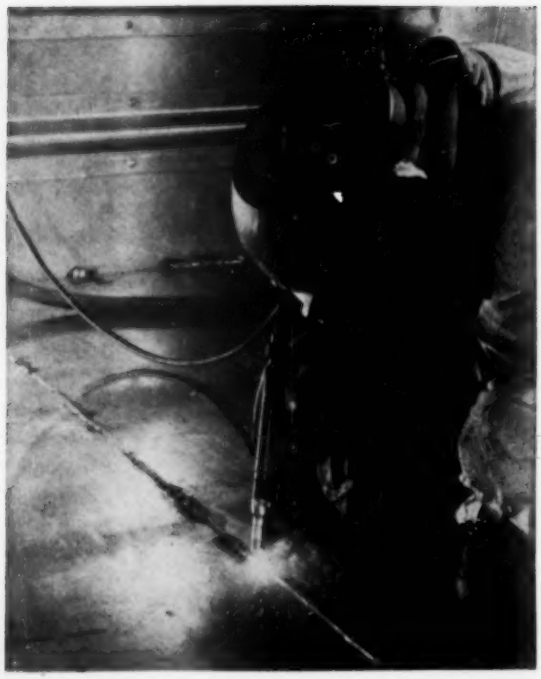


Fig. 75 Fabrication of aluminum dump truck bodies

Figure 72 is a photograph showing the interior of a prilling tower looking toward the top. This tower, used in prilling ammonium nitrate, is 20 ft in diameter and 122 ft high. It is constructed of $^{3}/_{16}$-in. thick aluminum plate material, types 3SF and 61ST. Fabrication required 3200 linear feet of welding all of which was accomplished with the inert-gas-shielded metal-arc welding process. Figure 73 is a view of an operator depositing an interior vertical weld and demonstrates the portability of the equipment.

The transportation industry has also found considerable use of the process in the fabrication of lightweight carriers. Figure 74 is a photograph of the interior of a shop engaged in the fabrication of aluminum tank cars used in the transportation of acids. The tanks are constructed of 2S, 3S and 61ST aluminum plates in

Fig. 76 Completed dump truck

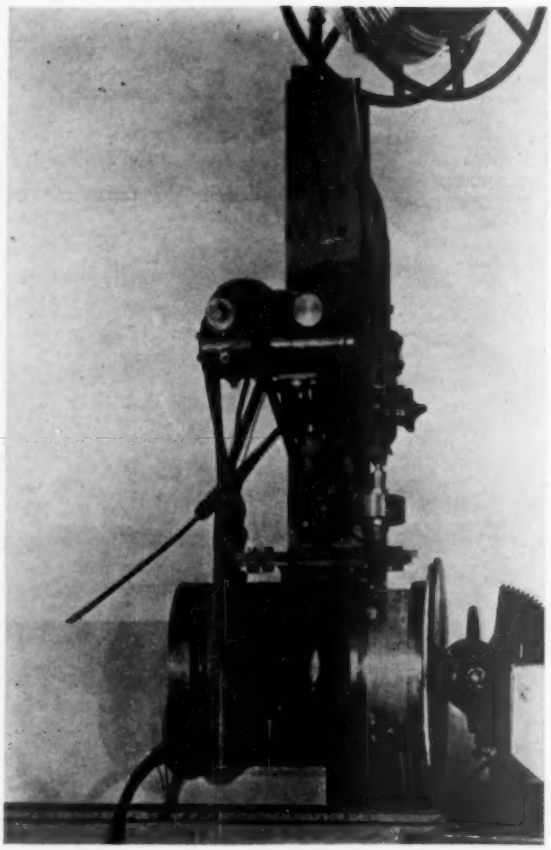


Fig. 77 Automatic setup for repairing Diesel engine piston

Fig. 78 Appearance of welded surface on Diesel engine piston

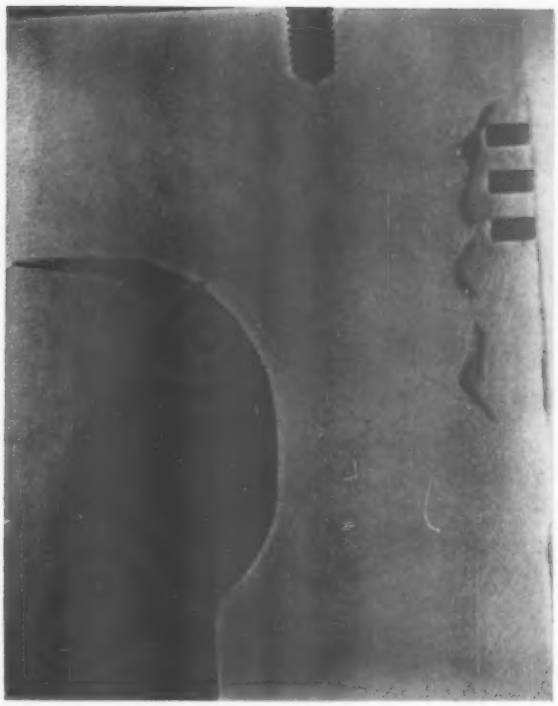


Fig. 79 Macrograph of a cross section through welded section

shell thicknesses of from $^1/_2$ to $^1/_8$ in. The tank shell is approximately 7 ft in diameter and 33 ft long. These tanks are fabricated using both the automatic and semi-automatic inert-gas-shielded metal-arc welding processes. Upon completion, all welds are X-rayed and must meet the requirements for steel welds established by the ASME boiler code.

A further illustration in the use of the process in fabricating transportation equipment is shown in Fig. 75. This operator is welding a transverse butt joint in the floor of an aluminum alloy dump truck body. A photograph of the completed body mounted on a truck chassis is shown in Fig. 76.

The inert-gas-shielded metal-arc welding process is finding wide use in maintenance and repair problems. One such problem is the rebuilding of the worn surfaces of high-strength, heat-resisting, copper, silicon, nickel, aluminum alloy pistons for Diesel engines. Figure 77 shows automatic inert-gas-shielded metal-arc welding equipment set up for this purpose. The worn ring grooves have been machined from the piston and it is in position so that the removed metal may be replaced by welding. The appearance of the surface of the piston upon completion of the weld is shown in Fig. 78. A macrograph showing a cross section of the piston through the welded repair is presented in Fig. 79. The quality and penetration of the weld are of particular interest.

The U. S. Navy has made wide use of the process for the welded fabrication of a number of aluminum alloy structures. Figure 80 is a photograph of a section of a submarine fair water constructed using 61-ST-6 aluminum alloy plate $^3/_{16}$ in. thick. This structure was completely welded using the inert-gas metal-arc welding process. 438 aluminum alloy wire was used as filler metal in depositing the welds.

Figure 81 is a view of a gun director mount also constructed using 61-ST-6 aluminum alloy. Except for the access hatch covers, this structure was completely welded using the inert-gas-shielded metal-arc welding process. Some idea as to the size of the gun director mount might be obtained by comparing it with the structural elements of the building at the rear of the photograph.

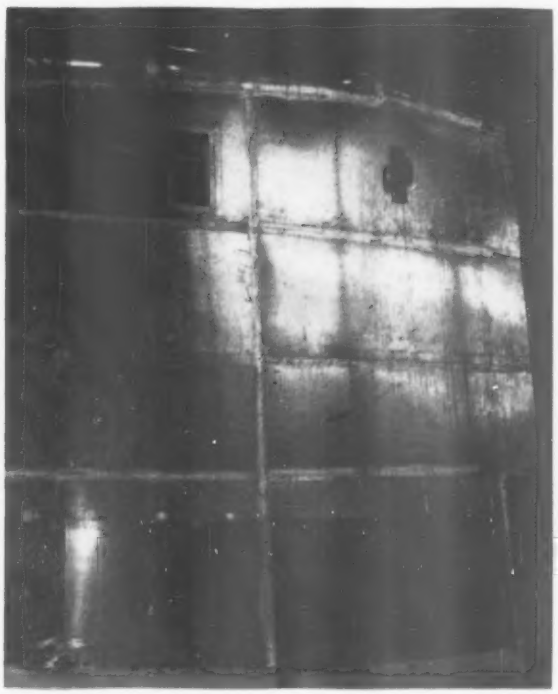


Fig. 80 Welded aluminum alloy submarine fair-water section

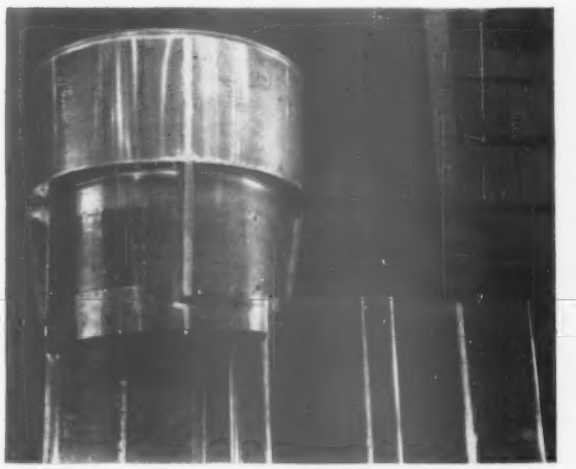


Fig. 81 Aluminum alloy gun director mount

Fig. 82 Upper section of a welded aluminum alloy tripod mast

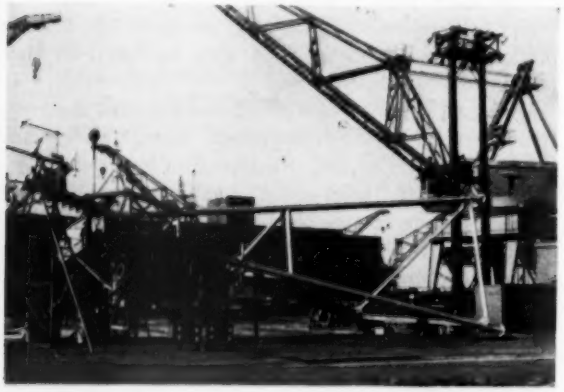


Fig. 83 Completed tripod mast

Aluminum alloy tripod masts have also been fabricated using this process. A photograph showing the upper section of this mast is presented in Fig. 82. The size of this section is readily indicated by comparison with the man shown on the upper platform. The completely assembled mast is shown in Fig. 83.

Aluminum alloy patrol torpedo boats have been fabricated using the inert-gas-shielded metal-arc welding process. Figure 84 is a photograph showing the structural components of the engine room of such a boat. All longitudinal framing has been welded intercostal to the transverse frames which presented a multiplicity of problems and demonstrates the usability of the welding equipment in confined and hard to reach locations. A photograph of the completed boat under

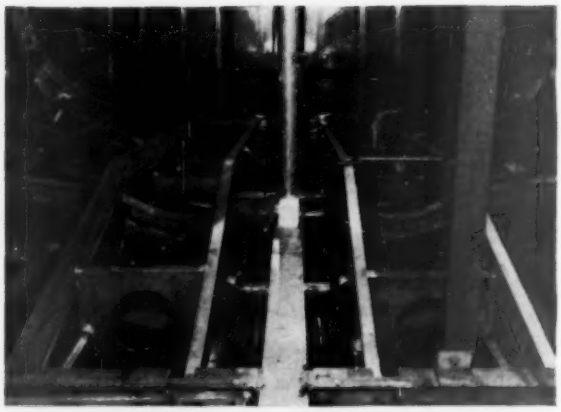


Fig. 84 Engine room of an aluminum patrol torpedo boat

Fig. 85 Patrol torpedo boat under way

way is presented in Fig. 85. The entire hull of this boat including its superstructure is fabricated from aluminum alloy materials and was completely welded using the inert-gas-shielded metal-arc welding process. All welds were subjected to X-ray examination and were required to meet stringent requirements for quality.

The application of the inert-gas-shielded metal-arc welding process in the fabrication of a large variety of aluminum and aluminum alloy structures is meeting with continued success. The wide range of material that has been welded, together with the many conditions and positions of welding, readily attest to the suitability of the process for this purpose. In fact, the inert-gas-shielded metal-arc welding process is rapidly replacing the inert-gas-shielded tungsten-arc and the covered electrode metal-arc welding processes previously used for the welding of aluminum and its alloys.

The inert-gas-shielded metal-arc welding process has been successfully used for the welding of metals other than aluminum. Copper, magnesium, nickel and steel together with their many alloys have presented no problem in welding by the use of this process. In general, the characteristics of the process are the same regardless of the composition of the electrode core wire. The most important feature of the equipment is its operation at high current densities. At these high currents, metal transfer is a spray of very small droplets which can be deposited in any position of welding.

Equally important is the flow of gas blanketing the welding operation. This must be of sufficient velocity to overcome the speed of welding and the surrounding atmospheric conditions. The simplicity of operation, speed of welding, automatic regulation and the freedom from slag make the process not only attractive to the operator but it provides an economic means for the joining of metals. Thus a process which 25 years ago was considered impractical has at last become a reality.

ACKNOWLEDGMENTS

The author gratefully acknowledges the cooperation of the Air Reduction Co., the Linde Air Products Co. and the Westinghouse Electric and Manufacturing Corp. in supplying many of the illustrations presented herein. Also the opportunity is taken to thank the members of the Metals Section, Industrial Test Laboratory, Philadelphia Naval Shipyard, for their efforts in collecting and presenting much of the data concerning the operating characteristics of the equipment. The help and assistance of Dr. Gilbert E. Doan in the preparation of this paper is also acknowledged. The permission of the Department of the Navy to publish this paper is equally appreciated.

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Steel Hardening, Flame. High-Speed Flame-Hardening,

(Continued on page 474)

the AMERICAN WELDING SOCIETY

activities • related events

Tentative Technical Program

AWS National Spring Meeting

Shamrock Hotel—Houston, Texas

June 16–19, 1953

Welding and cutting demonstrations will be featured at the Southwest Welding and Allied Industry Exposition to be held at the Hall of Exhibits, Shamrock Hotel, Houston.

Exposition hours—Tuesday and Wednesday 12 noon to 10 P.M.
Thursday and Friday 10 A.M. to 6 P.M.

TUESDAY MORNING, JUNE 16th—9:30 A.M.

Two Simultaneous Sessions

A—WELDING TITANIUM

Shamrock Room

Chairman—COL. THURSTON T. PAUL
Watertown Arsenal
Co-Chairman—CARL E. HARTBOWER
Watertown Arsenal

1. **Effect of Atmospheric Contaminants on Arc Welds in Titanium**
by J. C. BARRETT and I. R. LANE, JR., U. S. Bureau of Mines
2. **The Effects of Iron, Manganese, Chromium and Molybdenum on Welds in Titanium**
by G. B. GRABLE, C. B. VOLDRICH and G. E. FAULKNER, Battelle Memorial Institute
3. **Brazing of Titanium**
by J. M. PARKS and N. A. DeCECCO, Armour Research Foundation

B—HUMAN ELEMENT IN WELDING

Grecian Room

Chairman—T. B. JEFFERSON
The Welding Engineer
Co-Chairman—LEW GILBERT
Industry and Welding

1. **Human Elements and Problems in Welding**
by DAVID P. O'CONNOR, Department of Water and Power, City of Los Angeles
2. **Human Element in Welding**
by R. C. WILEY, California State Polytechnic College
3. **Radiography as an Educational Tool in European Welding Industry**
by HANS VINTER, Danish Central Welding Institution

TUESDAY AFTERNOON, JUNE 16th—2:00 P.M.

Two Simultaneous Sessions

C—WELDING TITANIUM

Shamrock Room

Chairman—C. B. VOLDRICH
Battelle Memorial Institute
Co-Chairman—J. J. CHYLE
A. O. Smith Corp.

1. **Brazing or Soldering Titanium Without Flux**
by HARLAN L. MEREDITH, North American Aviation Co.
2. **Restoration of Ductility in Alloy Titanium Welds**
by ALLAN J. ROSENBERG, E. HUTCHINSON and S. WEISS, General Electric Co.
3. **Spot Welding of Titanium—Carbon Alloys**
by E. F. HOLT, P. R. Mallory and Co., Inc., F. H. VANDENBURGH, Mallory-Sharon Titanium Corp., and N. L. McCLYMONDS, P. R. Mallory & Co. Inc.

D—RESISTANCE WELDING

Grecian Room

Chairman—J. H. COOPER
Taylor Winfield Corp.
Co-Chairman—E. L. BUCKINGHAM
Chance Vought Aircraft

1. **Flash and Pressure Weld Qualification Tests on 4340 Steel Heat Treated to 260–280,000 Psi After Welding**
by MARIO L. OCHIEANO, Lockheed Aircraft Corp.
2. **Basis for a Resistance Welding Specification for the Electronic Industry**
by PETER G. POETTO, CBC Welding Corp., STEPHEN A. MONTANARO and HAROLD SHARNEY, City Testing and Research Laboratory

Special Events

Thursday Afternoon and Evening, June 18th—Trip and Dinner

Trip to San Jacinto battleground by boat via ship channel or by bus at individual's option. Bus trip will pass refinery and chemical plants on Ship Channel. Trip starts 2:30 P.M. Tour of battleground, San Jacinto Monument and Museum and Battleship Texas. Terminates at famous San Jacinto Inn at 5:30 with Fellowship Hour provided with relaxing refreshments.

Captain's famous seafood dinner served at 7:00 P.M. Transportation back to Shamrock provided by bus at 9:30 P.M. Cost of trip $7.50 including transportation, cocktails and dinner.

Ladies Entertainment

Tuesday, June 16th—Luncheon, Fashion Show at Sakowitz Brothers

Wednesday, June 17th—Breakfast at Joskeys. Bus tour of Houston

Thursday, June 18th—Trip through Shamrock kitchens. Boat trip to San Jacinto. Social evening and Dinner per above.

Plants Visits

Plant Visits, see details page 426. For exact time, see bulletin board, Shamrock Hotel.

WEDNESDAY MORNING, JUNE 17th—9:30 A.M.

Three Simultaneous Sessions

A—RESISTANCE WELDING SYMPOSIUM

(Arranged by Technical Activities Committee)

Emerald Room

Chairman—J. J. MacKINNEY
The Budd Co.
Co-Chairman—E. A. BUSSARD
The Coleman Co.

1. **Instrumentation**
   Author to be announced later
   Moderators: C. R. DIXON, Aluminum Company of America; R. P. C. RASMUSEN, Battelle Memorial Institute; C. B. SMITH, Douglas Aircraft
2. **Techniques and Welding Schedules**
   by W. J. WILSON, Kaiser Metal Products
   Moderators: E. B. MORRIS, Grumman Aircraft Engineering Corp.; A. J. ROSENBERG, General Electric Co.; R. P. BECKER, International Harvester; M. L. OCHIEANO, Lockheed Aircraft Corp.

(*Continued in afternoon*)

B—CONSTRUCTION

Shamrock Room

Chairman—L. F. MEGOW
A. O. Smith Corp.
Co-Chairman—W. C. COX
General Electric Co.

1. **Applications of Medium Alloy, High-Strength Steel in Welded Construction**
   by HOWARD L. MILLER, Republic Steel Corp., and ARTHUR E. WILKOFF, Youngstown Steel Car Co.
2. **Applications of Plastic Theory**
   by W. S. ATKINS, College of Technology, Liverpool

C—ALUMINUM

Grecian Room

Chairman—G. O. HOGLUND
Aluminum Company of America
Co-Chairman—ALBERT MULLER
Air Reduction Research Lab.

1. **Recrystallization Welding**
   by JOHN M. PARKS, Armour Research Foundation
2. **Joining Aluminum to Other Metals**
   by MIKE A. MILLER, Aluminum Research Laboratories

WEDNESDAY AFTERNOON, JUNE 17th—2:00 P.M.

Three Simultaneous Sessions

D—RESISTANCE WELDING SYMPOSIUM

(Arranged by Technical Activities Committee)

Emerald Room

Chairman—J. J. MacKINNEY
The Budd Co.
Co-Chairman—E. A. BUSSARD
The Coleman Co.

3. **Production Quality Control**
   by FLOYD MATHEWS, Boeing Airplane Co.
   Moderators: WILSON SCOTT, Westinghouse Electric Corp.; HAROLD ROBINSON, Kaiser Aluminum; FRANK G. HARKINS, Solar Aircraft; J. B. HOUSTON, Intercontinental Mfg. Co.
4. **Applications**
   (*a*) Stainless Steel Aircraft
   by D. O. SAMUELSON, Solar Aircraft Co.
   (*b*) Aluminum Aircraft
   by C. B. SMITH, Douglas Aircraft Co.

E—STRUCTURAL WELDING

Shamrock Room

Chairman—A. AMIRIKIAN
Bureau of Yards and Docks
Co-Chairman—H. F. CRICK
Mosher Steel Co.

1. **Welded Rigid Connections for Portal Frames**
   by A. A. TOPRAC, University of Texas
2. **An Evaluation of Plastic Analysis as Applied to Structural Design**
   by B. G. JOHNSTON, University of Michigan, C. H. YANG and L. S. BEEDLE, Lehigh University
3. **Plastic Strength and Deflection of Continuous Beams**
   by K. E. KNUDSEN, C. H. YANG and L. S. BEEDLE, Lehigh University, and B. G. JOHNSTON, University of Michigan

F—INERT ARC WELDING

Grecian Room

Chairman—J. E. DATO
Linde Air Products Co.
Co-Chairman—M. G. WICKER
Air Reduction Magnolia Co.

1. **Inert-Arc Welding by the Fillerarc Process**
   by R. W. TUTHILL, General Electric Co.
2. **Stranded Electrode Materials for Aircomatic Welding**
   by H. ROBINSON, Kaiser Aluminum and Chemical Sales Co., and H. C. COOK, Air Reduction Laboratory
3. **Fusion Welding of Light-Gauge Alloys**
   by JACK T. MALONEY, Rohr Aircraft Corp.

THURSDAY MORNING, JUNE 18th—9:30 A.M.

Two Simultaneous Sessions

A—STORAGE TANKS AND PIPE LINES

Grecian Room

Chairman—JAMES EARTHMAN
Wyatt Metal & Boiler Works
Co-Chairman—M. E. HOLMBERG
Metallurgist Consultant

1. **Automatic Field Welding of Girth Joints of Large Storage Tanks**
   by PERRY C. ARNOLD, Chicago Bridge and Iron Co.
2. **Factors in the Low-Temperature Impact Strength of Carbon Steel**
   by J. R. WATT, University of Texas and J. J. SMETANA, University of Michigan
3. **The Use of Magnaflux for Quality Control of Pipe Line Welds**
   by GEORGE L. C. DEHN, Magnaflux Corp.

B—STAINLESS STEELS

Shamrock Room

Chairman—W. B. BROOKS
Dow Chemical Co.
Co-Chairman—M. A. SCHEIL
A. O. Smith Corporation

1. **Stabilizing Austenitic Chrome-Nickel Weld Metal Against Intergranular Corrosion**
   by H. C. CAMPBELL, Arcos Corp.
2. **Submerged-Arc Welded Vessel Linings**
   by JAMES G. KERR and ROBERT E. ANDERSON, C. F. Braun & Co.
3. **Heliarc Welding of Stainless Steel Piping**
   by F. J. PILIA, Linde Air Products Co.

THURSDAY AFTERNOON, JUNE 18th

2:30 P.M. Sightseeing Trip

5:30 P.M. San Jacinto Inn—Fellowship Hour and Cocktails

7:00 P.M. Captains Dinner

FRIDAY MORNING, JUNE 19th—9:30 A.M.

Two Simultaneous Sessions

A—ARC WELDING APPLICATIONS

Grecian Room

Chairman—A. WISLER
Hughes Tool Co.
Co-Chairman—F. H. BERRY
Big Three Welding Equipment

1. **Arc Welding of Ferritic and Austenitic Nodular Cast Iron**
by HARRY FISK, JESSE S. SOHN and WILLARD M. BOAM, Wright Aeronautical Div., Curtiss Wright Corp.
2. **Fusion Welding of Ductile Iron**
by T. E. KIHLGREN and H. C. WAUGH, International Nickel Co., Inc.
3. **Maintenance Welding in the Petroleum Industry**
by DON H. RASMUSSEN, Eutectic Welding Alloys Corp.

B—MARINE STRUCTURES

Shamrock Room

Chairman—E. C. RECHTIN
Bethlehem Steel Co.
Co-Chairman—T. J. DAWSON
Ingalls Shipbuilding Corp.

1. **Tricky Problems in Welded Ship Repair**
by MILTON FORMAN, Todd Shipyards Corp.
2. **Residual Stresses in Welds**
by BELA RONAY, U. S. Naval Engineering Experiment Station

Plant Visits

Interesting organized group plant visits are being arranged to the A. O. Smith Sheffield Pipe Plant and the new Houston plant of Brown and Root, at which places unique welding procedures will be seen on products in production. Transportation, by buses, will be provided from the Shamrock Hotel to the plants and return. Arrangements will also be made for small groups to visit other industrial plants of their selection.

EXHIBITORS AT AWS HOUSTON EXPOSITION
JUNE 16-19, 1953
As of March 27, 1953

Exhibitor	*Booth No.*	*Description of Display*
Acetegon Gas Co.	53	
Adams Alloy Co.	7	*Demonstration:* Metalite hard-facing alloys; acetylene, electric and carbon arc torch; hard facing; rebuilding of construction equipment parts, using special jigs and fixtures
Air Reduction Sales Co.	29, 108–119	*Demonstration:* Manual application of Aircomatic welding process; 6B Oxygraph multitorch cutting machine; Airco-Heliweld hard-facing process and machine tool cooling method with pure carbonic liquid CO_2
Aladdin Rod & Flux Mfg. Co.	37	*Demonstration:* Welding of zinc base metals and brazing or soldering of aluminum with Aladdin rod
Alloy Rods Co.	120–121	*Film:* "No Finer Electrodes Made Anywhere" shows manufacture of arc-welding electrode
All-State Welding Alloys Co., Inc.	54	*Demonstration:* Alloys and fluxes; unique work positioners; welding rods; metal cleaner and preservative
Aluminum Co. of America	32–34	*Demonstration:* Methods for arc welding the aluminum alloys; inert arc welding *Display:* Welded products
American Manganese Steel Div.	105–107	*Display:* Hard-facing electrodes; repointers; rods; grouser bars
Ampco Metal, Inc.	126–127	*Display:* Ampco-Trode, arc-welding electrodes, coils, filler rods; Ampco-Weld resistance welding alloys, electrodes, accessories
Arcair Co.	87–88	*Demonstration:* Arcair metal removal process
Arcos Corp.	63–64	*Display:* Stainless and low-hydrogen arc electrodes *Demonstration:* Oxyarc Process and Equipment for cutting stainless, nonferrous, and cast-iron materials
Aronson Machine Co.	8	*Demonstration:* Welding positioners
Atlas Welding Accessories	150	*Display:* Welder hand-chipping hammers, wire scratch brushes, identification marking stamps and hammers, hand chisels, welders' rules, electrode carrying case, drop-forged safety tongs
Bernard Welding Equipment Co.	147	*Display:* Electrode holder, mechanical hands weld cleaning hammers, welding torches
Big Three Welding Equipment Co. (Distributor for Nelson Stud Welding)	100–101	*Demonstration:* Nelson Stud-welding equipment

Welding & Allied Industry Exposition

The AMERICAN WELDING SOCIETY'S Exposition to be held June 16th through June 19th at the Shamrock Hotel Hall of Exhibits in Houston, Tex., appears, by present indications, to be an outstanding success. Key welding interests from all over the country are making advance arrangements to attend this gigantic all-welding exhibit.

Information from the more than 65 exhibitors—manufacturers of products for the welding and allied industries—indicates a wide variety of products will be exhibited many in actual use. Products shown will include: aluminum alloys and fluxes, silver brazing flux, stainless steel solder, positioners, contour and radius markers, centering heads, welding rods, electrodes, castings, miscellaneous brazing alloys, electrode holders, weld cleaning tools, magnetic particle inspection instrument, arc-welding equipment, welder caps, lighters, and chains, portable industrial X-ray units, regulators and torches.

Here under one roof will be demonstrated the products of many manufacturers who regularly sell products for welded fabrication, weldments, welding processing, gas cutting, brazing, finishing, tooling, gaging, testing, stress relieving, X-raying servicing and handling.

Action-type demonstration displays will be presented by Adams Alloy Co., All-State Welding Alloys Co., Dockson Corp., Handy and Harman, Hobart Brothers, J. M. Ragle Industries, Sonoflux Corp. and Stoody Co.; a full-length film on arc-welding electrode manufacture by Alloy Rod Co.; and many new and improved products are scheduled for initial showing at this AMERICAN WELDING SOCIETY sponsored show.

Exhibitor	*Booth No.*	*Description of Display*
Brush Electronics Co.	151	*
The Champion Rivet Co.	51–52	*Display:* Arc-welding electrodes
Contour Marker Corp. of Calif.	139–140	*Display:* Contour markers, radius markers, centering heads
Coyne Sales Co.	104	*Display:* Acetylene cylinders
Dockson Corp.	3	*Demonstration:* Torch-O-Matic acetylene gun; oxygen acetylene welding torches; cutting torches; tips; regulators (including air, CO_2); air-welding helmets; welders goggles and face shields
Eutectic Welding Alloys Corp.	45–49	*Demonstration:* EutecTrodes, EutecRods, Eutector temperature-indicating fluxes; oxy-acetylene joining
Gamma Industries, Inc	95	*
General Electric Co.	16–19	*Demonstration:* GE 60-10 electrodes using GE arc welder *Display:* Engine-driven d-c welder with trailer; synchronous precision welding control, cycle recorder, electro force gage
Handy & Harmon	30–31	*Demonstration:* Two silver-alloy brazing jobs, one using propane gas for heat on simple revolving table, the other at torch brazing table
Harnischfeger Corp.	35–36	*Demonstration:* Zip-Lift Hoist *Display:* DC-200 Rectifier Welder and TH-200 AC Welder
Heath Engineering Co.	9	*Display:* Ultra-Graph Torch Guilding Machine, plus circle-cutting attachment
The Hobart Brothers Co.	89–91	*Demonstration:* Arc-welding equipment (including gasoline-engine- and electric-motor-driven operators) *Display:* Welding electrodes and accessories
Holger Andreasen, Inc.	144	*Display:* Andrex lightweight portable X-ray units for industrial radiography
Houston Oxygen Co. & Smithweld Div.	96–97	*Demonstration:* Under water cutting by oxygen and hydrogen methods *Display:* Welding and cutting equipment gases
Industry and Welding (magazine)	Location "B"	*Display:* Welding magazines, merchandising and marketing information
International Nickel Co., Inc.	73–78 (Incl. 76A)	*Demonstration:* Procedures in joining of nickel and high nickel alloys
Jackson Products	71–72	*Display:* Arc-welding electrode holders; safety equipment (including helmets, goggles, eyeshields)
Lukens Steel Co.	68–70	
Magnaflux Corp.	4–5	*Demonstration:* Showing Magnaflux, Magnaglo, Zyglo and the new Spotcheck dye penetrant
Marquette Manufacturing Co.	141	*Display:* Welders; oxy-acetylene welding and cutting equipment; welding electrodes
Metal Goods Corp.	79	Local distributors for 8 exhibitors
Metal & Thermit Corp.	65–67	*Display:* Murex arc-welding electrodes welding accessories and a-c and d-c welders
Miller Electric Manufacturing Co.	50	*Demonstration:* SR and a-c welders
Mir-O-Col Alloy Co.	137–138	*Display:* Hard-facing electrodes
National Cylinder Gas Co.	10–15	*Demonstration:* Flame cutter; arc-welding apparatus *Display:* Transformers; cutting and welding apparatus
National Diamond Laboratory	142	*Display:* Industrial diamond wheel dressers, radius dressers, diamond turning tools, diamond lapping compounds, diamond hones and diamond points
National Torch Tip Co.	134	*Display:* Oxy-acetylene cutting and welding tips
Nelson Stud Welding Div., Gregory Industries	98–99	*Demonstration:* Lincoln arc welding; pipe-beveling machinery; positioner equipment
Page Steel & Wire Div., ACCO	146	*Display:* Stainless-steel coated electrodes; gas-welding rods; sigma wire on spools
Pandjiris Weldment Co.	26–27	*Demonstration:* Positioners, turning rolls, welding gantry; *Pictured:* Weldmore equipment
Cecil C. Peck Co.	43–44	*Display:* Automatic "Baby George" welder
Permalatem Welding Alloys Co.	123	*
Purnell Alloys Co.	143	*
J. M. Ragle Industries	136	*Demonstration:* White metal welding and brazing *Display:* Hose and cable measuring and cut-off machine, drill kits, soapstone holders, positioner, welders caps, clamps, lighter chains, lighters, fractional size drills, power grip wrenches, headbands, hose ferrule crimper

Successful Congress

An all-high record has been set for attendance, registration and sales-from-the-floor by the Western Metal Exposition and Congress held March 23rd to 27th in the Pan-Pacific auditorium and the Hotel Statler, Los Angeles.

Clocked attendance for the five-day show totaled 53,453 and registration added up to 33,648.

These figures were made public by William H. Eisenman, Cleveland, secretary, American Society for the Metals, who managed and directed the successful events for the Society.

"Success of the show and technical sessions," Mr. Eisenman stated, "assures repeat holdings of the combined events in Los Angeles on a two-year basis." He said a lease has been signed by ASM for Pan-Pacific auditorium dates of Mar. 21–25, 1955, with other dates reserved for 1957, 1959 and 1961.

Accomplishments of the show just concluded have prompted many exhibitors to file applications with ASM, 7301 Euclid Ave., Cleveland, to insure that space be held for them in the 1955 Los Angeles show.

Importance of Western Metal Congress sessions, presented by seven cooperating technical societies at the Hotel Statler was attested by large and studious audiences. The congress ran concurrently with the exposition.

"The sessions," Mr. Eisenman said, "were the best attended of all western metal meetings. Many sessions were jamed to capacity."

"The show," he continued, "was the biggest selling exhibit which ASM has operated in the West. Many exhibitors during the five days sold every item in their booths, and took orders for many more.

"Practically all participants have complimented ASM on a show in which lasting contacts were formed between exhibitors and customers, as well as potential buyers.

"Attendance naturally was heavier from the Los Angeles, San Francisco, Oakland and San Diego regions than other western areas. But many metal engineers and plant heads were present from all other parts of the West, with a liberal representation of casterners intent on seeing and hearing the latest developments.

"The large turnout is representative of the great recent industrial expansion in the West. New developments in metals and their fabrication find immediate application in the western area. The speed at which advances in metal engineering were pounced upon at the show and technical sessions indicates the western area can absorb and digest new developments as rapidly as they come out.

"With enormous research efforts going forward in Los Angeles and San Diego, it is obvious that scientific equipment will continue finding a ready market in the southwest and other western sections."

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WELDING and
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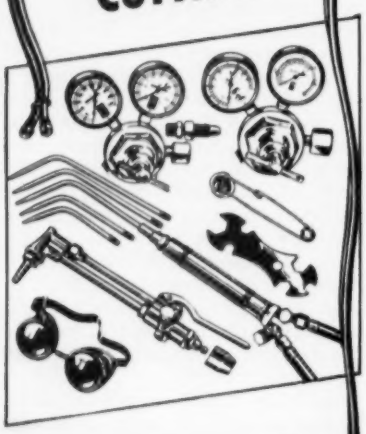

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1—C-2 Cutting Tip.
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1—No. 134-AD Acetylene Regulator, 60 lb. and 500 lb. gauges.
1—Commercial to P. O. L. Adaptor.
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4—Hose Connections.
1—Outfit Wrench.
1—Round File Gas Lighter.
1—Pr. Series 66-19-6 Welding Goggles.

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Exhibitor	*Booth No.*	*Description of Display*
Resistance Welder Manufacturers Assn.	1–2	*Display:* Resistance-welding samples submitted by members
Service Diamond Tool Co.	128	*Demonstration:* Hardness testing machines and accessories; also, brazing shims
Smith Welding Equipment Corp.	93–94	*Demonstration:* Torch bodies, cutting assemblies and cutting torches; ball bearing regulators; acetylene generators; a-c arc welders
Sonoflux Corp.	135	*Demonstration:* Model 3 magnetic particle inspection instrument
Stoody Co.	81–85	*Demonstration:* Automatic electric welding head; *Display:* Castings
Sylvania Electric Products, Inc.	28	*Display:* Tungsten electrodes (including new Zirtung zirconium rod)
Tempil® Corp.	125	*Display:* Temperature-indicating materials; high-temperature paints
John Tillman & Co.	129	*Display:* All-leather gloves, mittens, garments (including jackets, coats, strap and cape sleeves, aprons, overalls); rod holders, head gear pads, shoe protectors, hand shields, lighter holder, knee pads
Trindl Products Ltd.	124	*
Tweco Products Co.	55–56	*Demonstration:* Super-Mel insulation for Twecotong electrode holders, Lug-Set block and punch *Display:* Electrode holders, ground clamps, cable connectors, cable accessories
Union Carbide & Carbon Corp.	38–42 57–61 (Incl. 40A 59A)	*
United Specialty Corp.	131	*
United Wire & Supply Corp.	80	*Display:* Brazing alloys; fluxes
Velocity-Power Tool Co.	145	*Display:* Automatic acetylene-air gas torch
Vernon Tool Co., Ltd.	92	*Demonstration:* Flame cutter
Wagner Mfg. Co., Inc.	132	*
Wall Colmonoy Corp.	6	*Display:* Welding rods, electrodes, castings; Spraywed process; Spraywelder metal spray unit
Weiger, Weed & Co. Div.	102	*Display:* Electrodes, water-cooled holders, seam-welding wheels
Welding Alloys Mfg. Co.	148	*
The Welding Engineer	Location "A"	*Display:* Welding magazines, books, reprints, merchandising and marketing information
Weldwire Co., Inc.	133	*
Westinghouse Electric Corp.	20–25	*Display:* Portable Heliarc welding unit; automatic welding Weldomatic *Demonstration:* Phos-copper and Phos-silver brazing; industrial a-c welders, d-c arc welders (Type RA), engine-driven welders

NOTE: All product information shown was supplied to the AWS by exhibitors.
* Data not furnished to AWS by exhibitor.

Executive Committee and Board of Directors Meetings

The Second Meeting of the Executive Committe for the 1952–53 year and the Second Meeting of the Board of Directors for the same period were held at the Lord Baltimore Hotel, Baltimore, Md. The Executive Committee meeting was held on Thursday, Feb. 19, 1953, at 10:00 a.m. and the Board of Directors meeting on Friday, Feb. 20, 1953, at 10:00 A.M.

Attendants at the Executive Committee meeting were: *Members*—F. L. Plummer, *Chairman*, E. R. Seabloom, J. H. Humberstone, I. Morrison, H. E. Rockefeller and, M. S. Shane. *Staff*—J. G. Magrath, Secretary, AWS; F. J. Mooney, Asst. Sec., AWS. *Guests*—A. N. Kugler, Vice-Chairman, TAC; M. B. Lanier, Member Board of Directors and Chairman, Industry Advisory Committee; A. L. Lees, Chairman, Maryland Section; C. I. MacGuffie, Chairman, 1953 Exposition Committee; and J. L. Wilson, Chairman, TAC.

Attendants at the Board of Directors meeting were: *Members*—F. L. Plummer, *Chairman*, E. R. Seabloom, J. H. Humberstone, J. H. Blankenbuehler, L. M. Grover, D. B. Howard, C. H. Jennings, M. B. Lanier, H. E. Rockefeller, M. S. Shane, J. R. Stitt and C. B. Voldrich. *Staff*—J. G. Magrath, Secretary, AWS;

F. J. Mooney, Asst. Secretary, AWS. *Guests*—C. W. Allen. Treasurer, York Section; J. Forsyth, Treasurer, Maryland Section; R. A. Guenzel, Chairman, Philadelphia Section; A. N. Kugler, Vice-Chairman, TAC; A. L. Lees, Chairman, Maryland Section; F. A. Logue, first Vice-Chairman, York Section; C. I. MacGuffie, Chairman, 1953 Exposition Committee; L. H. Matthews, Secretary, Maryland Section; C. H. Pyle, Chairman, York Section; P. L. Stumpf, Member Executive Committee, York Section; and J. L. Wilson, Chairman, TAC.

Announcements

(*A*) At the Executive Committee meeting, Chairman Plummer advised that the Executive Committee at its meeting on Dec. 11, 1952, had decided to try out the procedure of having the Executive Committee meet the day prior to the meeting of the Board of Directors to review the agenda and, where necessary, further prepare the presentation of any items which would require studied consideration by the Board at its meeting the day following.

(*B*) At the Board of Directors meeting, Chairman Plummer advised the Board members regarding the meeting of the Executive Committee on the day previous, the reasons therefor, and stated that the Executive Committee had utilized the Board of Directors' agenda and as each item was introduced the recommendations of the Executive Committee would be given to the Board for its consideration.

TAC Recommendations

(*A*) TAC submitted its recommended practices for stress relief of austenitic steel weldments as prepared by the AWS Committee on Piping and Tubing and recommended the adoption of the Recommended Practices for Post-Weld Heat Treatment of Austenitic Steel Weldments as a tentative standard of AWS. The Chairman advised that the Executive Committee had reviewed this item and recommended approval thereof.

Action: Upon motion, duly seconded, it was voted to adopt the tentative standard.

(*B*) As a result of a conference of officers of TAC, the Chairman of the Educational Committee, and the Secretary of the SOCIETY, TAC recommended that the existing technical Committee on Minimum Requirements be transferred to the jurisdiction of the Educational Committee accompanied by the following additional recommendations:

1. The Committee on Minimum Requirements membership pattern be retained with respect to personnel; such to consist of representation from users, producers and vocational education.

2. Existing Committee on Minimum Requirements membership be retained as a nucleus for operation.

3. The Scope of the Committee encompass both the formulation of standards for and the promotion of training in welding.

4. That there be established suitable liaison between the Educational Committee and TAC through the medium of appointment by the Board of Directors, annually, of a representative selected by TAC to membership on the Educational Committee.

The reason for these recommendations is that both TAC and the Educational Committee recognize that one of the objectives of the Educational Committee is the promotion of welding education at the vocational school level. It was also agreed that the objectives of one of the subcommittees of the Educational Committee and the technical Committee on Minimum Requirements for Instruction of Welding Operators were parallel and that logically a committee dealing with education should operate under the jurisdiction of the Educational Committee. It was further recommended by TAC that A. N. Kugler (now a member of the Educational Committee) be designated as a representative of TAC on the Educational Committee . . . . The Society's Secretary read a recommendation from J. Heuschkel, Chairman of the Educational Committee, which represented the thinking of the Educational Committee at its meeting on Feb. 6, 1953, in Columbus, Ohio, and which indicated that the Educational Committee requested the Board of Directors to approve the policy of having a liaison member designated by TAC to the Educational Committee and that the Educational Committee was willing to accept the responsibility of the transfer of the technical Committee on Minimum Requirements for Instruction of Welding Operators to the jurisdiction of the Educational Committee but with the observation that the Educational Committee was in the process of reorganizing and formulating a proposed active program for 1953–54 and that it would be advisable that the transfer not be effected until toward the end of the fiscal year, at which time the Educational Committee would present its proposed activity and requirements therefor to the Board of Directors for consideration in its 1953–54 program . . . . The Educational Committee also requested that the Board of Directors approve the policy of having the Chairman of the Section Advisory Committee as a member of the Educational Committee and requested approval of the following additions to the Educational Committee: A. D. Althouse, F. Jonassen, J. G. Magrath, A. N. Martin and R. A. Wyant. Accordingly, the Executive Committee recommended to the Board of Directors that the approval of the transfer be provided as recommended by TAC and as acceptable to the Educational Committee but that the time of transfer be deferred until the close of the 1952–53 fiscal year (August 31st) but not later; all subject to

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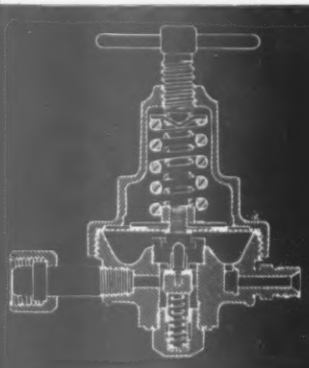

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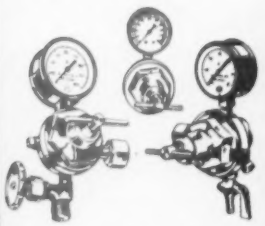

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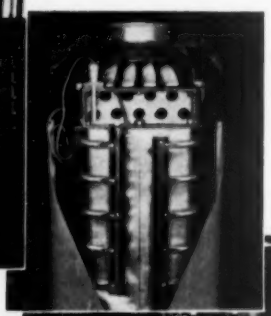

Copper tubes are first brazed to large copper tube manifolds (above) — and then jigged and brazed to copper jacket. 3/32" EASY-FLO 35 wire does these jobs using torch heating — time, jigging included, 10 minutes. The same basic construction is used in RUUD house heating boilers.

Copper finned tubes and bronze headers are assembled in jigs with 1/16" EASY-FLO 45 wire rings at each joint — then brazed by dipping in hot salt bath as you see below.

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Booths 30 and 31

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the Educational Committee's presentation to the Board of Directors, at its August 1953 meeting, of a recommended program of activity for the 1953-54 year, accompanied by a proposed budget, both of which must meet with Board approval; and approval of appointments to the Educational Committee as requested.

Action: Upon motion, duly seconded, the Board of Director approved of the above recommendations.

(*C*) TAC recommended to the Board of Directors that Alexander Gobus be appointed AWS Representative on ASA Sectional Committee *Z*-54—Safety in Industrial Use of X-ray. The Executive Committee recommended approval of this appointment.

Action: Upon motion, duly seconded, the Board of Directors so approved.

(*D*) The Board of Directors in January 1951 granted the technical Committee on Metallizing the right to solicit funds to cover expenses in an amount not to exceed $5000 for a corrosion test program involving the exposure of 5000 metallized steel specimens for periods varying from 1 to 12 years, with the stipulation that the funds must be raised within six months. $2625 was raised and $1215 has been expended for necessary items, leaving a balance of $1410. The Committee now needs approximately $2400 additional for the purchase of racks to replace racks loaned temporarily and now required by industry for their own use, and requests permission to solicit an additional $2500 from organizations interested in this type of program. The executive Committee recommended approval.

Action: Upon motion, duly seconded, the Board of Directors so approved.

(*E*) TAC through its Chairman, J. L. Wilson, pointed out that Rule 17 of "Rules to Govern Organization, Functions and Operations of Technical Committees of AWS" makes mandatory a circularization of proposed standards or proposed revisions of existing standards to a "representative group of interested individuals in industry." He observed that this requirement cannot always be followed and in many cases such wide circularization is not necessary. He therefore recommended a revision as follows:

Rule 17 (Committee Reports): "A technical committee shall, if so directed by TAC, circulate . . ."

Rule 17 now reads: "A technical committee shall circulate each proposed standard . . ."

The Executive Committee recommended approval of change.

Action: Upon motion, duly seconded, the Board of Directors so approved.

Assistant to Technical Secretary

As a matter of information, TAC advised that after an interview by J. L. Wilson, S. A. Greenberg, and J. G. Magrath, Albert B. Long was engaged to join the

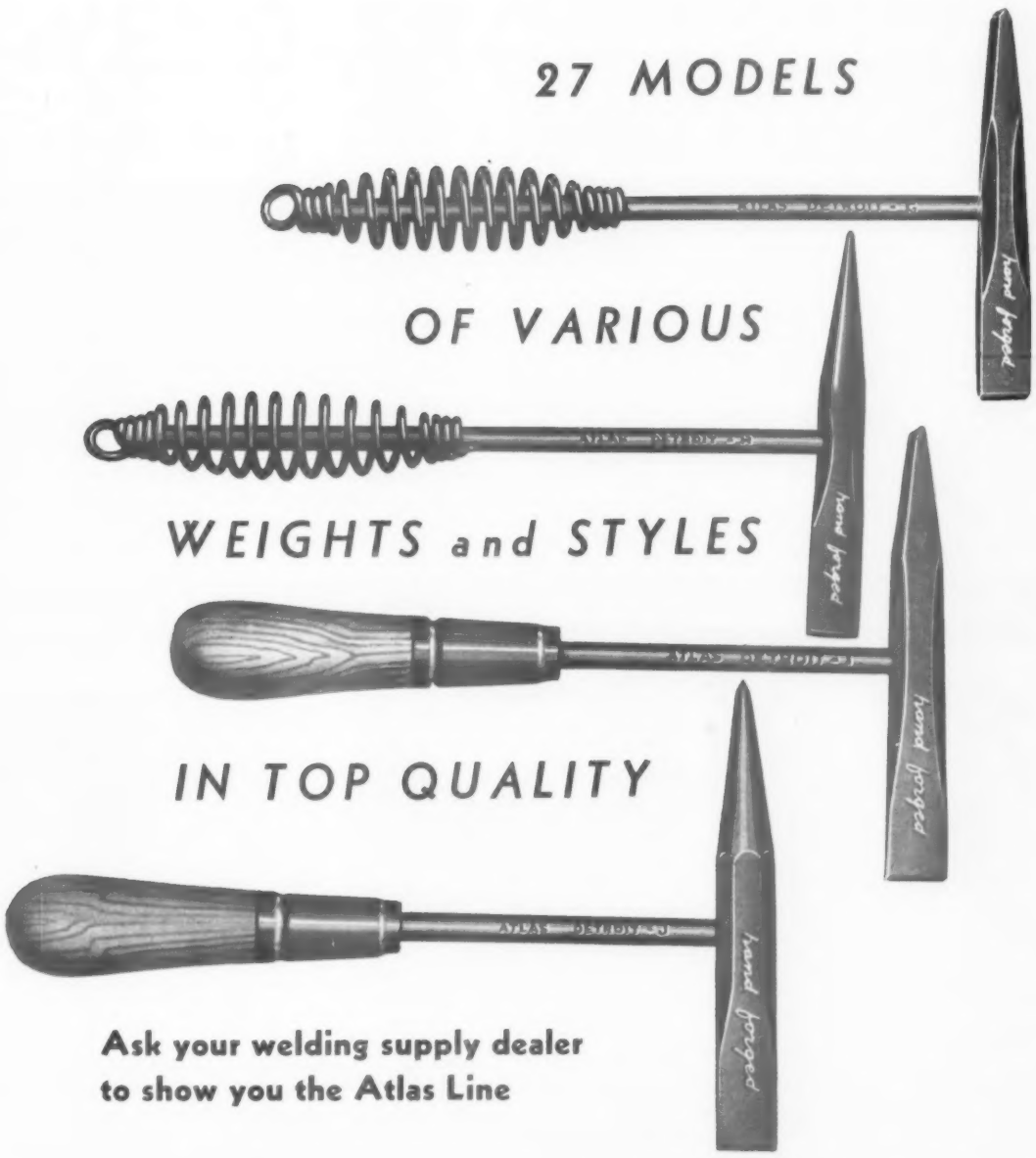
Tough as they come

27 MODELS

OF VARIOUS

WEIGHTS and STYLES

IN TOP QUALITY



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Society's technical staff as Assistant to the Technical Secretary, effective Feb. 2, 1953.

1953 Welding Exposition

C. I. MacGuffie, Chairman of the 1953 Exposition Committee, reported that on the basis of the first canvass for advance reservations, a little over 7000 of 10,000 available square feet had been reserved by industry. His Committee had had three meetings to date since its organization and an Exposition Manager, Robert T. Kenworthy, was engaged in the order as reported in the minutes of the Executive Committee meeting of Dec. 11, 1952. He outlined the arrangement for cooperation among the Exposition Committee, the Publicity Committee, and the Headquarters Staff. Contracts were mailed to exhibitors around the first of January on the basis of the original mailing list. As of the date of this Board meeting, 8700 sq ft total have been contracted for and the Exposition Committee is confident that there will be no financial burden on the SOCIETY. The Committee will call another meeting in March after the return of the Exposition Manager and the SOCIETY's Secretary from Houston. The Committee observed that its next job is to complete the sale of space and with the aid of the Publicity Committee to produce adequate trade releases that will result in a high attendance. The Committee expects to send out 100,000 invitation tickets through industry user and exhibitor promotion. The Executive Committee at its meeting received a complete report from Mr. MacGuffie's Committee and expressed its complete confidence in the Exposition Committee and its activities and recommended acceptance with appreciation of the Committee's report by the Board of Directors.

Action: The Board of Directors accepted with appreciation the foregoing report.

Northeast Tennessee Section

A group centered in and about the city of Oak Ridge, Tenn., has accomplished the enrollment of 73 new AWS members and fulfilled the necessary steps for the establishment of a Section. They formally request authority to operate as the Northeast Tennessee Section of AWS with headquarters at Oak Ridge, Tenn. The Executive Committee recommended approval.

Action: Upon motion, duly seconded, the Board so approved.

Reciprocal Membership

(*A*) R. L. Townsend, Chairman of the National Membership Committee, recommended that AWS and the National Welding Supply Assn. exchange membership.

(*B*) The South African Institution of Welding requested the exchange of membership with AWS.

The Constitution and By-Laws Committee advised that the foregoing can be accomplished by the Board of Directors voting to remit dues to NWSA and the SAIW Secretaries (By-Laws: Article IV, Section 5) in return for parallel action by NWSA and SAIW in favor of the AWS Secretary . . . . In discussion it was clarified that there would be no work imposed upon the Secretary, that while this suggestion was new in regard to an Association it had a number of precedents on the basis of reciprocal membership exchange between Societies, and further that in the case of reciprocal membership with NWSA, it did not involve the SOCIETY in any manner dangerous to its activity but rather, in both instances, would result in beneficial exchange of periodicals, information, bulletins and other data of interest to each other's group. The Executive Committee approved of the suggestions and recommended that the Board of Directors act on the matter of approval of remission of dues.

Action: Upon motion, duly seconded, the Board of Directors so approved.

Manufacturers Committee Scope

The Manufacturers Committee on June 10, 1952, President Jennings presiding, recommended that their scope be clarified and prepared for their consideration and in turn, upon their approval, submitted to the Board of Directors for its considera-

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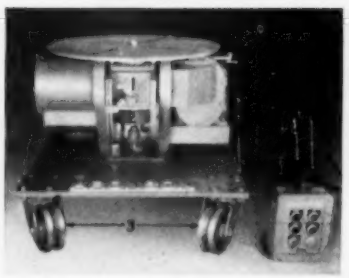
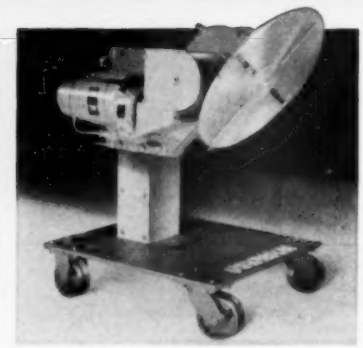
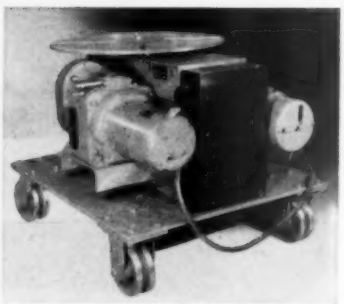


Front view shows 1-Free-Wheeling adjustment. 2-CYL Air Cylinder clamping device. 3-Front Casters swivel (rear casters rigid).



Quarter view shows chassis elevated. 135° table tilt — Tilt motor with brake.



Rear view shows Infinitely Variable Transmission with micrometer control — Magnetic reversing starters for Tilt and Rotation.

COMPARE . . .

1 SMALLEST 1000 lb. POSITIONER: 18" high, 30" wide, 34" long! COMPACT — MIGHTY!

2 HIGHEST PRECISION: 1% Speed Control; Minimum Backlash; 1° Tilt Accuracy!

3 MOST VERSATILE: ZERO to 3.75 RPM Table Rotation; Built-In Free-Wheeling; 20 seconds for Full Tilt with Magnetic Braking; Adjustable Table Height from a LOW 18" to a HIGH 32"; HOLLOW SPINDLE, tapped both ends; Precision Machined Table; Built-In MERCURY GROUND Main Spindle!

4 HIGHEST QUALITY: Anti-Friction Bearings Throughout, no bushings; Oil-Tight Dust-Tight Push Button Station at LOW VOLTAGE; Magnetic Reversing Starters; Aluminum Bronze Worm Gears; NO PERIODIC MAINTENANCE!

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WELD-ARC TYPES	TYPICAL WELD DEPOSIT ANALYSIS
7016	.70% Mn
7016 N	1.0% Ni
8016 N	3.30% Ni
9016 CM	1.0% Cr—.50% Mo
9016 MM	1.70% Mn—.40% Mo
9016 NCM	1.35% Ni—.55% Cr—1.40% Mn
10016 NM	1.70% Ni—1.35% Mn
10016 CM	2.40% Cr—.50% Mo
12016 NMV	1.75% Ni—1.25% Mn—.25% V

A FULL AND COMPLETE LINE OF NINE DIFFERENT LOW HYDROGEN ELECTRODES

HERMETICALLY SEALED in 10 lb. moisture-, dirt-, grease- and dust-proof all-metal containers immediately upon emerging from the baking oven.

SECURELY PACKED in oven-fresh condition, with 6 containers carefully cushioned from each other by inner carton; then placed in a sturdy outer carton to prevent possibility of any damage en route to you.

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THE FACTS ABOUT LOW HYDROGEN ELECTRODES

ALLOY RODS COMPANY
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SOUTHWESTERN PREMIERE * ALLOY RODS 22-MINUTE COLOR AND SOUND MOTION PICTURE "NO FINER ELECTRODES MADE . . . ANYWHERE" . . . SPACE 120-121, WELDING & ALLIED INDUSTRY EXPOSITION, HOTEL SHAMROCK, HOUSTON, JUNE 16-19.

tion and approval. The present scope of the Manufacturers Committee, as worded, might be interpreted as confining its activities to exposition matters only. The Board of Directors on Oct. 18, 1951, recommended that the Manufacturers Committee interest itself in all SOCIETY matters affecting their interest. Accordingly, the following scope, in addition to that covered by the present By-Law, has been prepared and approved by the current members of the Manufacturers Committee:

"To interest itself in those SOCIETY activities of concern to the manufacturers of welding machines, equipment and supplies, in policies relating thereto, and in ways and means for accomplishing the SOCIETY's objectives; to act in an advisory capacity to the SOCIETY's Board of Directors on matters of interest to the Committee; and to promote the SOCIETY's objectives to other manufacturers of welding machines, equipment and supplies, enlisting their active interest, support and participation therein."

This proposed addition to their scope is now submitted to the Board of Directors for approval and then for submission to the Constitution and By-Laws Committee for incorporation, properly worded, in the By-Law dealing with the scope of the Manufacturers Committee. The Executive Committee recommended approval by the Board of Directors and referendum to the Constitution and By-Laws Committee.

Action: Upon motion, duly seconded, the Board of Directors so approved.

Industry Advisory Committee Scope

The Board of Directors on Oct. 18, 1951, approved the creation of a new Standing Committee, *pro tem*, known as the Industry Advisory Committee, and gave power to the President to seek a Chairman for the Committee and prepare an outline of scope. The following proposed scope has been formulated:

"Industry Advisory Committee—An industry advisory committee comprised of representatives of users of welding equipment and supplies, which committee shall interest itself in those SOCIETY activities of concern to industry users of welding and its allied processes, in policies relating thereto, and in ways and means for accomplishing the SOCIETY's objectives; to act in an advisory capacity to the SOCIETY's Board of Directors on matters of interest to industry; and to promote the SOCIETY's objectives to other users of welding and its allied processes, enlisting their active interest, support and participation therein."

Action: Upon motion, duly seconded, the Board of Directors so approved.

Publicity Committee Replacement

Air Reduction Sales Co., who in the past has provided the services of C. A. McClean as a member of the 1952–53 Publicity Committee, advises that Mr. McClean has been transferred to another department and they desire to substitute Walter Goerg, Jr., in this activity. Accordingly, it is recommended that he replace Mr. McClean and the Executive Committee recommended this replacement to the Board.

Action: Upon motion, duly seconded, the Board of Directors so approved.

Policy Thermoplastic Joining

Question has arisen regarding the SOCIETY's policy in regard to thermoplastic joining of metals. The matter was discussed at the Executive Committee meeting of Dec. 11, 1952, and has been reopened. The Executive Committee recommended that thermoplastic joining of metals be accepted by the SOCIETY as a process falling within the range of its interest and in the category of "allied processes" as mentioned in the SOCIETY's By-Laws, as well as in the same order that soft soldering, metal spraying and flame treatment of metal are accepted as being of SOCIETY interest.

Action: Upon motion, duly seconded, the Board of Directors so approved.

Year Book Publication

The Secretary proposed that issues of the Year Book be printed in sections properly indexed, each section treating specifically with one of the Year Book's present departments in view of the fact that the data for each of these departments is completed at different times of the calendar

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125	275	450	1000	1550
138	288	500	1050	1600
150	300	550	1100	1650
163	313	600	1150	1700
175	325	650	1200	1750
188	338	700	1250	1800
200	350	750	1300	1850
213	363	800	1350	1900
225	375	850	1400	1950
238	388	900	1450	2000

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A convenient method of controlling working temperatures in:

- WELDING
- CASTING
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FREE — Tempil° "Basic Guide to Ferrous Metallurgy" — 16¼" by 21" plastic laminated wall chart in color. Send for sample pellets, stating temperature of interest to you.

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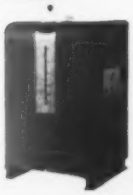
MODEL 100 Series Heavy Duty Industrial Arc Welder . . 7 models



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ARC WELDERS For Submerged Arc Welding 4 models

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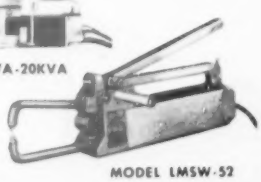

MODEL MSW

MODEL LMSW-52

year and if the whole awaits the binding in one volume, much of the information is outdated and likewise a great deal of the information is delayed reaching the parties interested. In order to legally provide for this change it will be necessary to revise sections of Article XV of the By-Laws. The revisions and a vehicle letter are provided in Attachment 18 as addressed to Mr. Hill. Chairman of the By-Laws Committee. The Secretary recommended approval of these changes and referendum of the suggested rewording of By-Law to the Constitution and By-Laws Committee for proper and legal wording. After review and discussion, the Executive Committee recommended that the Board of Directors approve these changes, and that a complete bound volume—master copy—of each year's releases be maintained at National Headquarters.

Action: Upon motion, duly seconded, the Board of Directors so approved, with additional provision that these sections be punched in suitable fashion in binder form.

SEE PROGRAM
HOUSTON MEETING
Page 424
PLAN TO ATTEND

AN OPPORTUNITY

is presented to all AWS Membership and Industry to secure back numbers of The Welding Journal Bound Volumes at very low cost.

Effective now, a limited supply of the following BOUND VOLUMES are available at the prices shown

Year	*Price	Year	*Price
1930	$4.00	1938	$ 4.00
1931	4.00	1948	8.00
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* Plus Postage

Each consists of the twelve (12) issues of that year's JOURNALS, each volume attractively bound in imitation black leather covers. These are valuable additions to your engineering and welding library. Place order now with the AMERICAN WELDING SOCIETY, 33 West 39th Street, New York 18, N. Y. Add 3% sales tax on N.Y.C. orders.

Employment Service Bulletin

Position Vacant

V-291. Position available, welding instructor for a leading Pacific Coast university. Bachelor's Degree necessary; Master's Degree desirable, as is some industrial experience. Position opens Oct. 1, 1953.

Services Available

A-636. Plant Manager, Plant Superintendent or Welding Engineer. Age 40. Over twenty years' experience in metal fabrication as Welding Engineer, Plant Superintendent, Quality Control, Production Manager and Foreman. Fourteen years' supervisory experience in methods, procedures, time and cost estimating, development, experimental and production work. Prefer connection with medium size organization engaged in welding and allied operations requiring managerial ability based on practical experience.

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Welding Research Engineer for varied research program of major petroleum refiner, location Chicago. Graduate metallurgist or mechanical engineer, preferably M.S. with welding training, with experience in welding research. Reply with details of education and experience and salary requirements. Replies held confidential. **Box V-292.**

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EUTECTIC WELDING ALLOYS CORPORATION

$2000

PRIZE COMPETITION FOR CONTRIBUTIONS TO THE SCIENCE AND ART OF "NON-FUSION" WELDING, BRAZING AND SOLDERING

Rules:

OPEN TO:
Engineers, Metallurgists, Research Investigators, Welders, Students, Faculty Members and all others qualified.

Covering technological and research aspects, procedures and applications of the use of lower melting (lower than parent) filler metals in the non-fusion welding processes.

The Jury and Committee of Awards:

1. Dr. Robert Humphrey, former Vice Chairman, American Society for Metals
2. Prof. Otto H. Henry, Dept. of Metallurgy, Polytechnic Institute of Brooklyn
3. Dr. Th. I. Leston, Vice President, Eutectic Welding Alloys Corporation

ELIGIBILITY

1. The Prize Contest is open to single individuals or groups of two or more, except employees of the Eutectic Welding Alloys Corporation, its subsidiaries and affiliates, its Advertising Agencies and its Distributors.

2. Each paper submitted must be original and previously unpublished. Moreover, each contestant must have actively participated in the work and preparation of the subject matter of the manuscript.

3. Participation necessitates submission of a paper of not less than 1,000 words, exclusive of drawings, specifications, tables, photographs, etc.

SUBJECT MATTER

1. The subject matter shall pertain to one of the following:

Classification A—*Basic principles, theory and results of research* in the field of "non-fusion" welding, brazing or soldering. (The metallurgical considerations of these processes may include Surface Alloying, diffusion, wetting, spreading, fluxing, equilibrium and non-equilibrium reactions, solidification, etc.).

Classification B—*Practical welding applications*—(The manuscript may be based upon the design or redesign of equipment, structures, and other products of ferrous or non-ferrous materials fabricated by "non-fusion" welding, brazing or soldering. Technical advantages of these processes and savings in material and labor should be considered and substantiated. Improvements in brazing and soldering techniques might also be the subject of the manuscript.)

2. Photographs, drawings, charts or test data which will add clarity to the presentation should be included.

SUBMISSION

1. Manuscripts should be typed in English, double spaced on 8½" x 11" white paper, with any drawing and photographs on separate sheets, preferably attached to the text. The manuscript should be securely bound and have a protecting cover.

2. Papers must be submitted in duplicate. One copy must be signed by the author (or authors) and enclosed in a separate sealed envelope, with the following information on the cover sheet (1st page) of the manuscript and on the outside of the envelope:

Name
Address
Signature
Company (or University) affiliation
Classification ("A" or "B") under which paper is submitted.

A duplicate of the paper, unsigned and unidentified as to author and application, should be enclosed in a second envelope.

The two envelopes should be placed in a large envelope and mailed to The Secretary, Prize Competition, Eutectic Welding Alloys Corporation, 172nd Street and Northern Boulevard, Flushing 58, New York, N. Y.

This procedure insures that all manuscripts are treated confidentially by the Jury. After the unidentified papers have been judged, the identification with the original paper on file with the secretary will be made and the prizes will be paid to the winners.

JUDGING

The papers will be judged by the Jury and Committee of Awards. In classification "A" the primary considerations are (1) originality, (2) understanding of basic principles, (3) merit of research results, (4) clarity of illustrations and data presented. In classification "B" the primary considerations are (1) originality, (2) material and labor savings, (3) improvement in efficiency and service life and (4) design and welding procedures.

Decision of the judges will be final. All entries and ideas become the property of The Eutectic Welding Alloys Corporation, and none will be returned.

CONTEST DEADLINE

All manuscripts have to be submitted and postmarked no later than August 31, 1953. Winners of awards will be notified approximately within (60) days after the close of the competition.

All communications and questions should be addressed to The Secretary, Prize Competition, Eutectic Welding Alloys Corporation, 172nd Street and Northern Boulevard, Flushing 58, New York.

Helpful suggestions on the preparation of the paper and on possible topics are available and will be sent upon request.

AWARDS

CLASSIFICATION A: Basic Principles, Theory and Results of Research		CLASSIFICATION B: Practical Welding Applications	
First Prize	$500	First Prize	$200
Second Prize	300	2 Second Prizes, each	100
Third Prize	200	3 Third Prizes, each	50
3 Fourth Prizes, each	100		
3 Fifth Prizes, each	50		

EUTECTIC WELDING ALLOYS CORPORATION
172nd Street and Northern Boulevard, Flushing, New York

Please send me ..... "Helpful suggestions on the preparation of papers for the EUTECTIC Prize Competition and Program of Awards."

Name .....

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WJ-5

NEWS OF THE INDUSTRY

Society for Experimental Stress Analysis Meeting

The Society's 1953 Spring Meeting will be held May 20–22, 1953, at the Hotel Schroeder, Milwaukee, Wis. This meeting will feature Panel Discussions, Plant Trips, and Social Diversion.

Tweco Opens New Branch

Tweco Products Co., Wichita, Kan., has just opened a new Branch Plant at Harper, Kan. The new location is 50 miles southwest of Wichita which permits material and personnel transfer in little more than one hour's time. The new plant building has approximately 7000 ft of floor space, half of which is devoted to machine shops and assembly area. The primary function of the Harper operation will be to serve as a feeder of parts and assemblies to the Wichita plant where final assembly and shipment is made.

International Institute of Welding Meeting

The International Institute of Welding will hold its Annual Meeting in Copenhagen, Denmark, July 5–10, 1953. Any member desiring to attend should communicate at once with Society headquarters.

Alloy Rods Co. Names Three Distributors

Alloy Rods Co., York., Pa., leading manufacturer of alloy arc-welding electrodes, has added three more distributors to its growing national distributor organization, according to an announcement from E. R. Walsh III, general sales manager.

The new distributors are: Cohoes Welding Works, 157 Saratoga St., Cohoes, N. Y.; Lincoln Welding Supply Co., 330 S. 10th St., Lincoln, Neb.; and Sommerfield Welding Supply Co., Inc., 56 Light St., Oshkosh, Wis.

Welded Plate Girder Bridges in Russia

According to a Russian magazine Golovkin, M. P., *Avtogennoe Delo*, 23 (5), 16–20 (1952)], all-welded plate girder bridges were put into mass production for the first time in Russia in 1950. The bridges are 75- and 109-ft spans. The 75-ft bridges consist of two plate girders. The web plate of each girder is 1/2 in. thick, 79 in. high. Each flange consists of two plates, the inner being 13 1/2 in. wide and 1 3/4 in. thick, the outer being 8 in. wide and 2 in. thick. The two plates are welded together. The web plates have vertical stiffeners. The girders are made of steel containing 0.16 C, 0.47 Mn, 0.23, Si, 0.04 S, 0.03 P. Automatic and semiautomatic welding is done with a manganese steel welding rod. The welded bridges require 28% less man hours than a similar riveted design.

New Film Available on Continuous Casting

A new, full-color, 35-mm sound-slide film, describing the patented ASARCO process for continuous casting of bronze rods, tubes and shapes, has been completed by the Continuous-Cast Products Department, American Smelting and Refining Co., Barber, N. J. It is available to interested groups without obligation.

The film is in two parts of about 15 min each. The first section describes in brilliant color transparencies the history of the process, its engineering details and its results. The second emphasizes typical applications for which this unique materials is used in industrial plants.

Technical societies, professional clubs, schools, engineering staffs or other groups interested in this instructive film can call or write the Continuous-Cast Products Department, American Smelting and Refining Co., Barber, N. J. Where possible, a lecturer will be provided; the film is available free.

Symposium on "Management Problems in the Use of Radioisotopes in Industry" Planned

Radioisotopes were a scientific curiosity a few years ago. Today they have taken their place as a new tool of value across a wide spectrum of industrial operations. In many fields, radioisotopes rival—and even surpass—electronic tools as controls in continuous process operations, as inexpensive and effective testing devices, and as time and labor savers in oil-well logging. These are only three of many ways in which radioisotopes are improving quality and lowering production costs.

In view of increasing use of radioisotopes in industry, a two-day symposium on special management problems arising from their use will be held at Oak Ridge, Tenn., on April 30th and May 1st. Industrial organizations using radioisotopes or planning to use them in the near future are invited to send management representatives to the symposium, which is being given by the Special Training Division of the Oak Ridge Institute of Nuclear Studies in cooperation with the Atomic Energy Commission. The Institute has trained more than 1300 scientists from throughout the world in the techniques of using radioisotopes in research.

The symposium will immediately follow a two-week advanced course in radioisotope techniques in industry. The course is intended for research personnel, while the symposium is intended for management personnel.

A fee of $25, payable at registration, will be charged for participation in the symposium. Advance enrollment is necessary to participate in the Oak Ridge National Laboratory tour and to obtain housing.

Additional information on the symposium and application forms may be obtained from the Special Training Division, Oak Ridge Institute of Nuclear Studies, P. O. Box 117, Oak Ridge, Tenn.

ASTM Committee A-1 on Steel

Departing from its usual practice of meeting during the winter in the East or Midwest, Committee A-1 held a series of meetings in Birmingham, Ala., from February 3rd to 5th, inclusive. The meetings were extremely well attended by over 150 members, and many constructive recommendations were made to the Committee by the eleven subcommittees which participated.

Officers of Committee A-1 are: *Chairman:* N. L. Mochel, Westinghouse Electric Corp., Philadelphia, Pa. *Secretary:* J. S. Worth, Bethlehem Steel Co., Inc., Bethlehem, Pa.

Structural

The Subcommittee on Structural Steel has been cooperating with the General Services Administration and the American Welding Society looking toward the development of a suitable specification for weldable steel. At present comments are being submitted on Interim Federal Specifications QQ-S-00741 and QQ-S-741. The need for another grade of steel for plates over 1 3/4 in. in thickness in Specification A 131 for ship steel has been noted and recommendations made to cover this situation. The range of ultimate tensile strength for shapes furnished to Specification A 7 T will be changed from "60,000 to 72,000" to "60,000 to 75,000" psi.

Carrying hot steel for THREE YEARS

and these Hard-Faced rollers are still in use

Three years ago, some cast iron cone rollers for this cooling bed were hard-faced with HAYNES alloy No. 92. Today, they are still carrying hot steel bars despite the continual impact, abrasion, and heat to which they have been subjected. Cast steel rollers on the same line, which were hard-faced with HAYNES STELLITE alloy No. 6, have also shown exceptional service – although they have not yet been in use as long as the cast iron ones.

HAYNES alloy No. 92, an iron-base alloy recommended for the cast iron parts, is exceptionally easy to apply by oxy-acetylene welding. It has a very low melting point and the molten alloy is quite fluid. Deposits have a Rockwell C hardness of 62-67 and excellent wear resistance.

HAYNES STELLITE alloy No. 6, the cobalt-base alloy used for hard-facing the cast steel parts, can be applied by metallic arc welding. Deposits are machinable and have excellent resistance to abrasion and heat.

For information on how to hard-face cast iron and cast steel parts, and on the alloys recommended for each job, write for a copy of "HAYNES Hard-Facing Manual."

HAYNES TRADE-MARK *alloys*

"Haynes" and "Haynes Stellite" are trade-marks of Union Carbide and Carbon Corporation.

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A Division of
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Pipe and Tubing

In Specifications A 161, A 200 and A 271 covering still tubes for refinery service it is proposed to change the weight tolerances from "3½ per cent over and 5 per cent under" to be "5 per cent over and under." Also an explanation as to how the weight is calculated will be added. In the interests of standardization and elimination of discrepancies the flange test requirements for welded tubing furnished to Specifications A 178, A 226, A 249, and A 250 are recommended for revision. An existing tentative revision to Standard Specification A 271 for seamless austenitic chromium-nickel steel still tubes covers the reduction of the number of tension tests required. It is recommended to adopt this as standard and also to similarly revise Standard Specification A 268 for seamless and welded ferritic stainless steel tubing.

Plates for Pressure Vessels

In order to permit Specification A 300 to cover steel plates suitable for temperatures down to minus 325 F, the 9% nickel steel covered by Specification A 353 will be included. A provision for stress relieving this steel at 1025 to 1085 F will also be added.

High-Temperature Pipe

Because of objections of the Boiler Code Committee of the ASME to certain provisions of Specification A 155 for electric-fusion-welded pipe it has been decided to eliminate class 2 and reword the specification to comply with Sections I and VIII of the ASME Boiler Construction Code. A proposed new specification for seamless ferritic alloy steel forged and bored pipe is under consideration in Subcommittee XXII. This specification will cover ten grades of steel.

Aluminum Radiators for Autos Seen in Offing

As a result of the extensive experimental work now under way, tomorrow's automobiles are likely to have aluminum radiators. This is one of many applications now being actively researched by automotive and aluminum manufacturers which undoubtedly will lead to greater use of the lightweight metal in motor vehicles of all types.

For many years, aluminum has been used extensively in trucks and busses where its light weight means greater payloads, and its resistance to corrosion means longer life with less maintenance. These uses are increasing. One truck manufacturer has been using aluminum in radiator top and bottom tanks and side columns in the form of castings. Some of these have been in operation for about four years, and to date no failures have been reported.

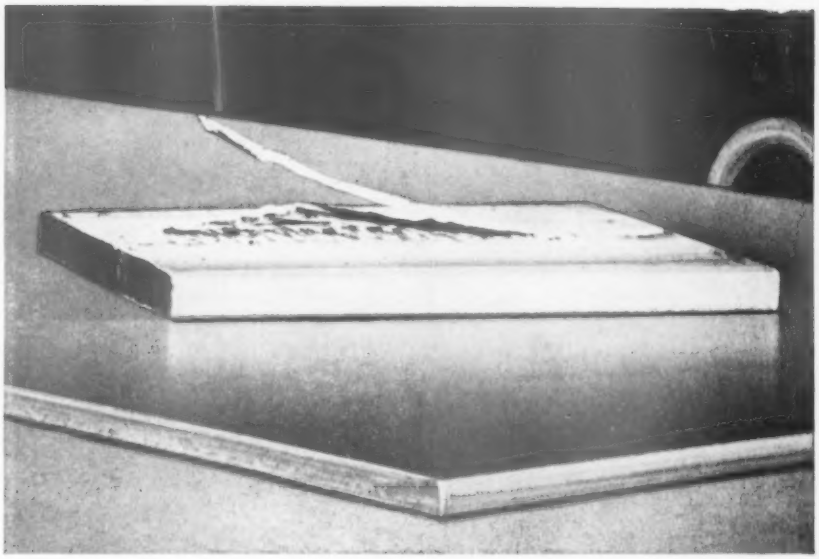
A survey of leading automotive manufacturers conducted by The Aluminum Assn. shows that a number of all-aluminum radiators are now in experimental use under service conditions. One large manufacturer, for example, has 35 radiators in use in different parts of the country. These have been deliberately placed in territories where conditions might be most severe. All have been operating satisfactorily for over a year with individual mileages ranging up to 30,000 and more.

Much of the research on this use of the lightweight metal has been aimed toward developing the best method of fabrication. Experience gained with brazed heat exchangers used extensively in aircraft has pointed toward a brazed assembly for automobile radiators. A brazed aluminum radiator can be operated at all cooling system pressures currently being considered. This characteristic is one which for some time has been in demand by automobile manufacturers. Problems involved in the manufacture of brazed aluminum radiators on a production basis are nearing solution.

Other possible methods of fabrication also are being thoroughly investigated. These include soldering aluminum fins to aluminum tubes or to brass tubes. Developments now are under way to make these methods more feasible.

CHAMPION
"Wear Devil A" Electrodes increase hook service life as much as three times!
Li'l Champ says:
Edges are hard surfaced prior to placing equipment in service.
Let us tell you more about "Wear Devil A" Electrodes. Write for full information.
Field tests prove that "Wear Devil A" deposits on the wearing edges afford impact and abrasion resistance far superior to that of non surfaced grappling hooks.
Due to excellent bond between weld and base metal, "Wear Devil A" deposits will not spall or crack despite the most severe service conditions.
When hooks have become worn they can be resurfaced without having to remove any of the old deposit.
Hardness averages 53 — 58 Rockwell C.
THE CHAMPION RIVET CO.
CLEVELAND 5, OHIO • EAST CHICAGO, IND.

This weld in Nickel-Clad Steel shows the self-lifting slag which the "141" nickel electrode gives when there is a proper balance in the welding conditions.



New Inco Electrode for Nickel-Clad Steel

"141" Nickel Electrode makes possible high ductility in iron-diluted nickel welds

The new Inco "141" nickel electrode for Nickel-Clad Steel is a companion to the Inco "131" nickel electrode for solid Nickel. Its new core wire and new flux make it possible to obtain high ductility when welding the clad side of Nickel-Clad Steel ... overlaying nickel on steel ... welding nickel to steel.

"141" is corrosion-resisting. Welds made with the "141" electrode on Nickel-Clad Steel or overlays on steel will have corrosion resistance comparable to that of solid nickel, providing adequate control is exercised over the iron dilution of the welds.

"141" meets Code requirements. Welds made with the "141" nickel electrode meet the requirements of the A.S.M.E. Unfired Pressure Vessel Code for construction of units covered by Case 896 (Clad Steels) and Case 1078 (applied linings).

Slag removal is easy, too. When the balance between heat input, speed of welding and iron dilution is right, the slag will lift from the weld about 3 inches behind the arc.

Mechanical Properties

(a) Nickel overlays on steel will have a minimum elongation of 30 per cent.

(b) Welds in the clad side of Nickel-Clad Steel will have a minimum elongation of 30 per cent.

(c) Welds in solid nickel will have a minimum elongation of 20 per cent.

(d) All weld metal tensile specimens (iron free) have the following properties:

Minimum yield strength (.2% offset) .....30,000 psi.
Minimum tensile strength .....65,000 psi.
(Hardness) Rockwell B 70-80

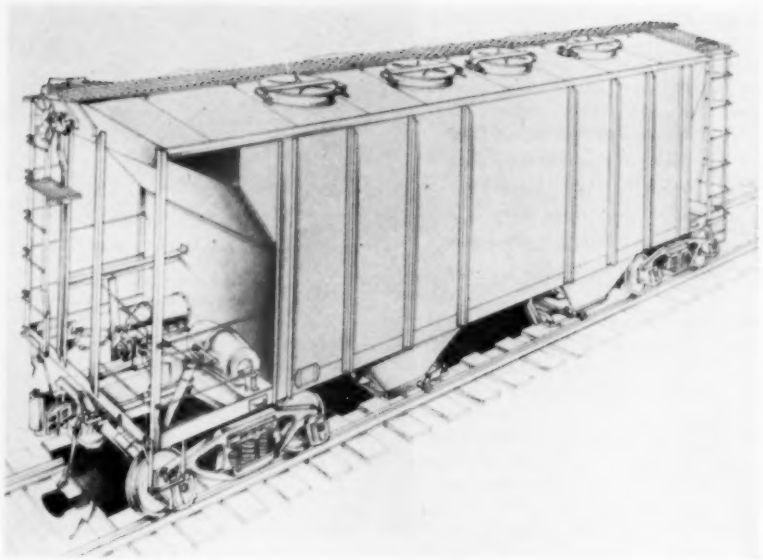
Consult your Distributor of Inco Welding Materials for the latest information on deliveries or assistance with special welding problems. Remember, too – it always helps to anticipate your requirements well in advance.

By the way, if you're at the AWS Welding Show at the Shamrock Hotel, Houston, June 16-19, drop in at our booth (73-78).

INCO TRADE MARK

THE INTERNATIONAL NICKEL COMPANY, INC.
67 Wall Street, New York 5, N. Y.

The favorable long-term prospects of the lightweight metal are causing automotive manufacturers to intensify their development work. On the basis of results achieved so far, the use of aluminum in this essential automotive component is expected to become economically feasible in the foreseeable future.



Standardized Freight Car

Pullman-Standard Car Manufacturing Co., nation's largest producer of railroad freight and passenger cars, recently announced through its president, C. W. Bryan, Jr., development of a new standardized freight car—an all-welded 70-ton covered hopper car.

The car, designated as the PS-2, is the result of rapidly increasing interest in covered hopper cars by railroads, shippers and consignees for the shipment of bulk commodities, and contains many new features and improvements over conventional cars of this type.

Like its standardized predecessor—the PS-1 box car, which was introduced to the railroads in 1947 by Pullman-Standard—the PS-2 covered hopper is built mainly of parts designed and manufactured by the carbuilder.

"Through standardization of design, the all-welded covered hopper car, like the PS-1 box car, lends itself to mass production," Mr. Bryan said. "That permits greater use of better and more expensive equipment and results in a quality car, efficiently produced at lower cost."

Success of Pullman-Standard's first standardized car—the PS-1 box car, is attested in the fact that more than 50,000 of these cars have been delivered or are on order since its introduction in 1947. The car has accounted for 30% of all box cars ordered in the postwar period and its adaptability to mass production has helped greatly in aiding the railroads to combat a shortage of freight equipment.

The PS-2 covered hopper, improved in a number of important particulars, already has demonstrated the general soundness of its structural features in severe static and dynamic tests of a prototype car in Pullman-Standard's Research Development laboratories at Hammond, Ind. Among its outstanding features are all-welded construction, which eliminates pockets and ledges and provides for fast clearing and cleaning; circular, weathertight hatches instead of the conventional square hatches; self-clearing hopper chutes a stronger, safer, cleaner roof, and a light weight of 46,400 lb.

Mr. Byran said that Pullman-Standard expects to be ready to build the new type covered hopper car in production quantities by the third quarter of 1953.

AT THE FRONTIERS OF PROGRESS YOU'LL FIND

AN AIR REDUCTION PRODUCT

For Welding and Cutting . . .

NATIONAL CARBIDE

in the red drum

HIGHEST QUALITY
DUST FREE

Write for the name and address of the NATIONAL CARBIDE supplier nearest you.

National Carbide Company

GENERAL OFFICES: 60 EAST 42ND STREET, NEW YORK 17, N. Y.

A DIVISION OF AIR REDUCTION COMPANY, INCORPORATED

Heliarc Welding of Aluminum Chairs

Shielded-inert-gas welding was used by the Barcalo Manufacturing Co., of Buffalo, N. Y., to help speed the production of 1200 aluminum deck chairs. The chairs, which are used aboard the *S. S. United States*, have to be lightweight, yet strong, and had to be delivered quickly. In order to meet these time and quality specifications, the manufacturer used Heliarc welding.

The chairs were fabricated from extruded aluminum tubing, $1^1/_2$ by $^7/_8$ in. and $^5/_{64}$ in. thick. The metal was prepared for welding by deoxidation in an Oakite No. 34 bath. Then, with the pieces clamped in a special jig, the operator used an HW-4 Heliarc torch to make

PANDJIRIS

Advanced Engineering takes the "Guess Work" out of POSITIONED WELDING!

Extensive research, plus specific planning "on the job", has resulted in many unusual installations of PANDJIRIS WELDMORE POSITIONERS in outstanding industrial plants and construction projects.

A wide variety of standard and special positioners are available — PANDJIRIS Engineered. A few are pictured here.

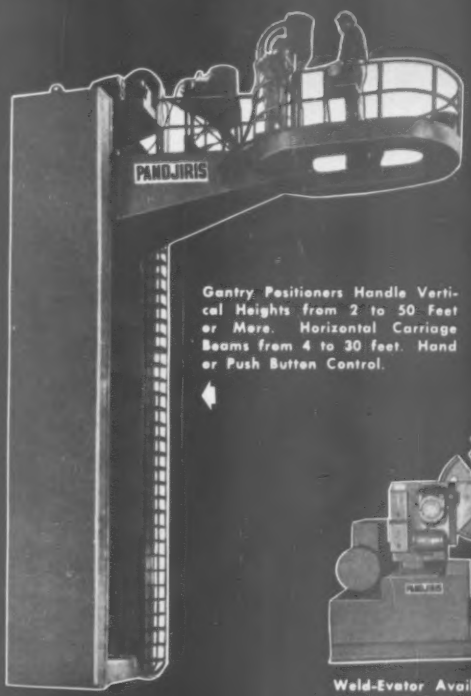
Put your specific welding procedures up to PANDJIRIS ENGINEERS . . . and a brief consultation will result in definite savings for you in production and installation costs.

Send for illustrated descriptive bulletins!

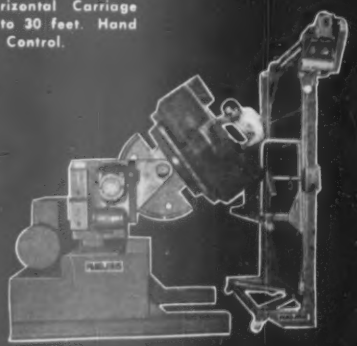
40,000 lb. Tilting Rotating Positioner with Hydraulic, Vertical Table Adjustment, Remote Control.

100 lb. Positioner — Tilting and Rotating. Manual Control.

Positioners in Capacities from 100 lbs. to 60,000 lbs. with 360 Degree Rotation . . . 135 Degree Tilt . . . Variable Table Elevations. Latest Literature: Bulletins EP-11 and EP-12.

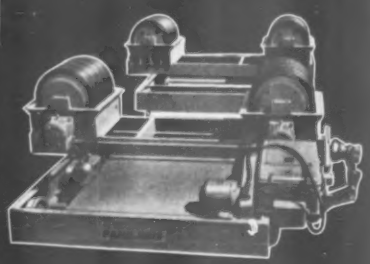


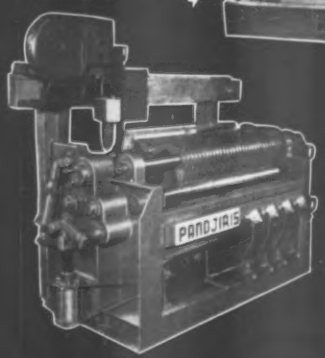
Gantry Positioners Handle Vertical Heights from 2 to 50 Feet or More. Horizontal Carriage Beams from 4 to 30 feet. Hand or Push Button Control.



Weld-Evator Available in Sizes from 4 to 30 Feet Elevations. Raises Welder to Exact Position for Down Hand Welding. Entire Unit is Portable.

Turning Rolls with Capacities from 2500 lbs. to 150,000 lbs. Small Models Available with Power and Idler Rolls Mounted in Same Frame. All Models Available with Self-Propelled and Idler Cars. Illustrated Literature Available.





Mandrel Positioners for Weld Seaming of Metal Parts in Sizes from 6 to 120 Inches, Inside Dimensions. Full or Semi-Automatic Operation. Push Button Control.

SEE YOU at HOUSTON!

A.W.S. Welding Exposition, June 16 to 19

PW

PANDJIRIS WELDMENT CO.

5151 NORTHRUP — ST. LOUIS 10, MO.

Fig. 1 The flexibility of the HW-4 Heliarc torch allows the operator to make clean, sound welds rapidly

Fig. 2 Because argon shields the welding operation, little finishing is necessary. Total welding time required for this chair is 1 hr.

the necessary butt and seam welds. This portable, easy-to-use torch proved to be ideal for this type of work. There were 16 ft of welds per chair. The finished welds were sound and clean, and required little finishing. Total welding time for each chair was 1 hr.

After welding and grinding, the chairs were "alodized" and given a coat of corrosion-resistant paint. The finished chair is sturdy, rustproof and fireproof.

Multi-Hydromatic Representatives

Richard B. Joy, Jr., President of Multi-Hydromatic Welding and Manufacturing Co., East Detroit, Mich., named the Robert H. Newton Co. of Cleveland as Multi-Hydromatic representatives.

The Robert H. Newton Co. prosecutes the sales of Multi-Hydromatic resistance-welding equipment throughout Ohio and nine counties in western Pennsylvania. Mr. Joy stated that the Newton firm now handles the complete line of both standard and special equipment engineered and manufactured by Multi-Hydromatic.

Immediately after graduating from the

University of Michigan, and before establishing his present business, Robert H. Newton joined the Lincoln Electric Co., of Cleveland, with whom he spent 22 years. During this association, Mr. Newton rose from Service Man to Sales Manager.

Mr. Newton implements his firm with a wealth of experience and a broad background in a great variety of industrial fields. He has personal experience in product design, tooling, metallurgy, general manufacture and welding procedure control.

The Robert H. Newton Co. makes its headquarters at 13125 Shaker Square, Cleveland 20, Ohio.

Glenn E. Smith Promoted

Tweco Products Co., Wichita, Kan., has announced the appointment of Glenn E. Smith as West Coast representative. He has taken up residence in San Jose, Calif.,

BOTH WORTH LOOKING INTO-
MANGANAL
11% - 13½% Manganese-Nickel Steel
THE TOUGHEST METAL KNOWN—
For Speedy and Low-Cost Replacement of Worn Equipment Parts.
MANGANAL
YOUR MANGANAL DISTRIBUTOR
An organization of skilled craftsmen that you can depend on for sound advice, to save time and money on the repair and rebuilding of heavy equipment.
MANGANAL
U.S. Patents 1,876,736—1,947,167—2,021,945
11%-13½% Manganese-Nickel Steel
• APPLICATOR BARS • WEDGE BARS
• SPECIAL SHAPE APPLICATOR BARS
• HOT ROLLED PLATES • SPECIAL TITE-KOTE AND BARE WELDING ELECTRODES
• SEAGO HARD SURFACING WELDING ELECTRODES
FREE WALL CHART
New edition illustrating 23 actual size WEDGE BARS with dimensions and weights, for easy reference.
WRITE TODAY!
Send for FREE helpful tips on speedy and economical repair of worn equipment.
NEAREST DISTRIBUTOR UPON REQUEST
STULZ-SICKLES CO.
SOLE PRODUCERS 92 N. J. RAILROAD AVE. NEWARK, N. J.

and will cover seven western states including California, Oregon, Washington, Idaho, Nevada, Utah and Arizona.

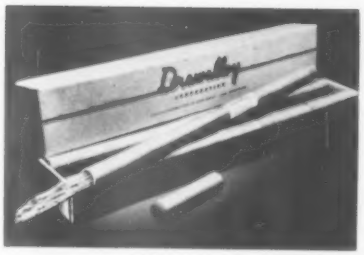
In the three years that he has spent with Tweco, Mr. Smith has worked in various departments of the company and is well qualified to fill this important new assignment. His main duty will be to work with Tweco distributors in the area.

Drawalloy Moves to New Quarters

The Drawalloy Corp., a wire mill producing stainless and tool steel wire for the welding industry, has expanded its operations and manufacturing facilities with new and enlarged quarters on Lincoln Highway West at Alloy Street, York, Pa., according to E. J. Brady, president.

This wire mill was established exclusively for the production of stainless steel, tool steel and special alloy wire for the welding industry, including coiled stainless wire for all types of automatic welding.

Large inventories of hot-rolled rod and in-process wire of the special chemical analyses required for welding are maintained. Finished stocks of cut wire for gas and inert arc welding are maintained in all grades of stainless wire and the five common types of tool steel: water hardening, oil hardening, air hardening, hot work and high speed.



Drawalloy Corp. has introduced a new form of package protection for its products, designed to simplify handling and shelving problems of both jobber and ultimate consumer. Ten pounds of bare wire in cut lengths are packed in clearly marked, sturdy fiber tubes with removable and replaceable caps. Six of these tubes are packed in attractively labeled corrugated shipping cartons. Simplified packaging in 10-lb tubes and 60-lb shipping cartons, the management believes, is an advance over such past methods as 50-lb burlap wrapping and 100-lb wood boxes containing cut lengths.

Mr. Brady, president of Drawalloy, is also founder and president of the Alloy Rods Co., York, Pa., leading manufacturer of alloy arc-welding electrodes.

Magrath Participates in Launching

Joe Magrath, while visiting Pascagoula, attended and spoke at the launching ceremonies for LST 1163. This was the third of a group of five of these ships that are now under construction by the Ingalls Shipbuilding Corp., Pascagoula, Miss.

Fig. 1

Figure 1 shows J. G. Magrath with Earl S. Shulters, Technical Representative of the United States Maritime Administration and Chairman of the Pascagoula Section of the AMERICAN WELDING SOCIETY.

Fig. 2

Figure 2 shows LST 1163 sliding down the ways into the waters of the Singing River where it will be towed to the Outfitting Berth for completion.

X-Ray Quality Welds in Aluminum Castings

One of the country's largest aluminum foundries is now using Heliarc welding to correct imperfect castings. The castings, some of which are for vital defense production, must pass rigid quality inspections. Imperfections—sometimes several in a single piece—must be eliminated. The foundry uses a special line for this reclamation work. They find that Heliarc

"Trindl is tops"

Says William Murray, Chicago Stadium Engineer

And that's not all—This Trindl 160A Arc Welder saved the Stadium thousands of dollars in time and labor costs. These low cost, high-quality welders are designed to handle production work with perfection eliminating costly work stoppage as Mr. Murray's letter testifies.

This is an actual photo of the Trindl 160A Welder in operation on the Chicago Stadium job. Complete details and illustrated literature on the remarkable performance of the Trindl Constellation line available. Contact your local dealer or write Dept. T50-E for information.

There is a Trindl Constellation Welder to suit every job at a cost to fit every budget. 8 Models from 30 to 400 Amperes unconditionally guaranteed for 12 months.

Trindl "100 TESTED" ARC WELDERS

TRINDL PRODUCTS LTD., 17 East 23rd Street, Chicago 16, Ill.

Mechanize 3 out of 5 sigma* hand

You can mechanize a lot of your manual sigma* welding applications with LINDE's new, lightweight SWM-3 machine. One man handles this easily portable machine—it weighs only 40 lbs.—and it's flexible. It can be mounted on a wall, a post, a carriage, or on a tractor-type machine, depending on the work at hand . . . And best of all, this machine can "think"—through LINDE's electronic voltage control.

Arc voltage control is a LINDE development for machine sigma welding. Set up out of the way, the voltage control instantaneously speeds up or slows down wire feed speed as required by changing arc conditions. The result is that you get smooth, uniform welds through proper control of welding variables.

LINDE'S ELECTRONIC VOLTAGE CONTROL

How many of *your* welding problems are due to a fluctuating voltage? How many? Well, you can eliminate them *all* with LINDE's electronic voltage control. It holds welding voltage substantially constant at any preset value within the welding range. It responds to increases or decreases in arc voltage by speeding up or slowing down the wire feed motor. This action is practically instantaneous and constant arc voltage results.

The voltage control unit is mounted either locally or remote from the machine. Set up near the welding generator or transformer, it makes the welding head (rod drive and wire reel section) small and compact—easy to handle.

One Knob Control

After making several basic adjustments that set the SWM-3 for a specific job, the machine practically works by itself. Just throw the switch to start welding. It's as easy as that. One simple knob is all you turn.

Quick, Easy Starts

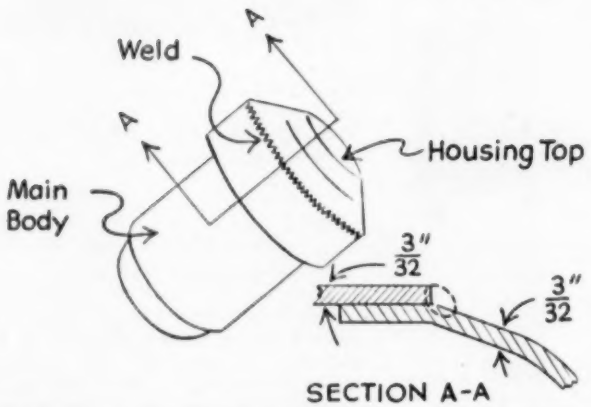
Use the retract starter built into the voltage control . . . turn on the wire feed switch, and the retract starter automatically causes the wire to:

1. feed down until it touches the work,
2. retract from the work, drawing an arc, and
3. start feeding down again, maintaining the preset welding arc voltage.

Ample Power

Because of a high operating voltage built right into the control, the wire feed motor gets ample power for smooth, efficient operation.

A Typical Application



LINDE's SWM-3 welds most metals fabricated commercially—aluminum alloys, stainless steel, carbon steel, deoxidized copper, Everdur, and aluminum bronze. Butt, lap, fillet, or corner welds are made in these metals from 16 gauge thickness upward.

This steel compressor housing is now being fabricated with LINDE's new SWM-3 machine for sigma welding. Lap welds in the 3/16-in. material are made at 55 in. per minute. Current is 380 amp. dcrp, using 3/16-in. welding wire.

* Initial letters of *S*hielded *I*nert *G*as *M*etal *A*rc. "Sigma" is easier to say.

welding jobs with this little machine with the big brain

HERE'S ALL YOU NEED RIGHT AT THE WORK

Welding Head

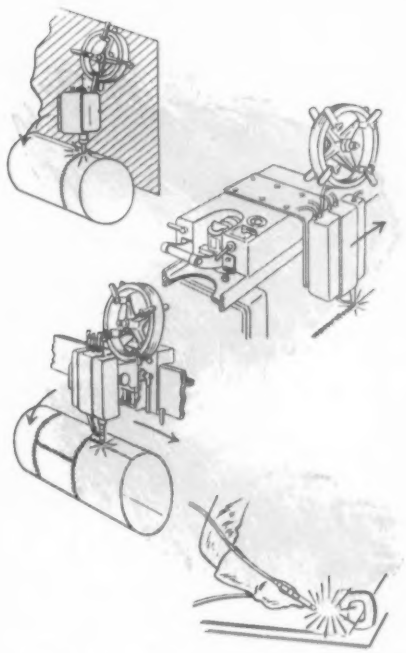
Net Weight . . . . . 40 lbs.

It houses . . . . . wire drive, wire-straightening device, water-cooled cup, wire guide tube and holder

It handles . . . . . 1/32, 3/64, 1/16, 3/32, welding wires

LINDE'S *dependable electronic voltage control unit.*

LINDE'S SWM-3 IS FLEXIBLE



USE IT IN A STATIONARY POSITION

Set up the welding head on a wall, post, or vertical bracket . . . Move the work to be welded beneath it. You can use the SWM-3 for many jobs in this position—it will handle four different sizes of welding wire.

GIVE IT MOTION

Mount the welding head on the OXWELD CM-37 tractor-type machine carriage . . . The SWM-3 will make longitudinal welds in cylinders, or butt, lap, and fillet welds in aluminum and stainless or carbon steels.

COMBINE BOTH SETUPS

It's just as easy to mount the SWM-3 on the OXWELD OM-48 side beam carriage: Use it for making longitudinal welds in any part. Stop the unit, revolve the work, and you can make circumferential welds in the same part—*without changing the setup.*

OR, USE IT MANUALLY

By adding an adaptor, you can use the SWM-3 with your sigma hand welding torch. It becomes a flexible drive unit to help you handle all of your other jobs that do not lend themselves to mechanization.

Ask LINDE to tell you more about the SWM-3 . . . There's a good chance that it will help you do one of your present welding jobs better, easier, faster, and cheaper. Telephone or write the nearest LINDE office today.

LINDE AIR PRODUCTS COMPANY

A Division of Union Carbide and Carbon Corporation

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The terms "Linde" and "Oxweld" are registered trade-marks of Union Carbide and Carbon Corporation

Fig. 1 Repairing rough areas on an aluminum casting. The portable Heliarc torch is ideal for a high-speed, high-quality weld

Fig. 2 Heliarc welding produces welds of X-ray quality. This casting, which is for defense work, must pass rigid inspections

Oxweld powder-cutting blowpipe cuts up manganese-bronze castings for remelting

welding helps them maintain top output by doing the job quickly and economically.

Usually the only preparation required is grinding, although preheating is used if the area to be welded is particularly large. After the necessary preparation, the welding is done with a Heliarc torch—and with special rods cast by the foundry. The Heliarc torch provides the flexibility necessary to produce high-quality welds quickly. Every weld is X-ray tested before the casting is released for assembly.

Previously, this welding was done by other welding processes. However, the Heliarc process proved to be much faster—and could be relied upon to produce X-ray quality welds.

Powder-Cutting Manganese-Bronze Scrap

Manganese-bronze castings 13 in. thick are cut up for remelting by powder cutting in less than half the time needed to cold-saw similar castings that are only 4 in. thick. Reclaiming the 3 tons of metal for commercial castings saves one foundry about $2000, since the price of manganese-bronze is about $700 per ton.

The castings were made as part of an experimental program to develop accurate flywheels for antimagnetic Diesel engines. Until recently they would have been cut up for remelting by the time- and blade-consuming process of cold sawing. Now an Oxweld powder-cutting blowpipe slices them quickly and easily.

KNU-VISE pliers help speed aircraft production

Twenty-two Knu-Vise toggle-action pliers accompany this huge aircraft assembly jig when delivered to a prominent airplane manufacturer. The pliers play an important part in attaching longerons and aluminum angles to section of fuselage.

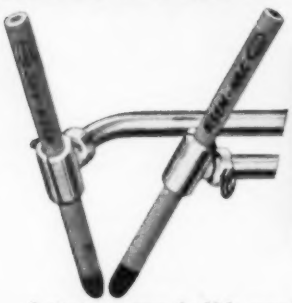
This job shows one of the countless ways in which Knu-Vise pliers and clamps are used to facilitate production.

Three Knu-Vise models selected for their high efficiency in specific operations: P-400, P-1200, P-1800.

Photo, courtesy of Bonner Die & Fixture Co., Detroit.

KNU-VISE PRODUCTS LAPEER MFG. CO.
3066 DAVISON ROAD • LAPEER, MICHIGAN

BECKER
KEEN-ARC CARBONS



FOR CONSISTENTLY GOOD RESULTS

Designed to carry the high currents necessary for intense heat, BBB Keen-Arc Carbons produce a fine-grained weld of high tensile strength. They give a smooth, steady "flowing" flame which does not wander and which is concentrated at the desired focal point. Flame temperature is easily and accurately adjusted by merely changing the ampere input, and heavy copper coating permits gripping at extreme ends—eliminates frequent and periodic resetting.

A COMPLETE LINE OF CARBON WELDING SUPPLIES including carbon and graphite electrodes, carbon rods and plates, welding paste, etc.
Write for catalog.

BECKER BROTHERS CARBON CO.
3450 South 52nd Ave. Cicero 50, Illinois

Remember the trade marks "tt" and "TUBE-TURN" are applicable only to products of TUBE TURNS, INC.

Engineered for tough service

THIS TUBE-TURN Welding Neck Flange will contain greater pressures under temperature extremes, and will last longer than other types under repeated bending or vibrations of piping. It is *engineered* for tough service . . . with a long, tapered hub, and a smooth transition in thickness to the pipe-end bevel.

You can select the exact Welding Flanges you require from TUBE TURN's complete line: welding neck; slip-on; lap joint; socket welding; blind; orifice; or pipeline non-standard flanges. It *pays to specify* TUBE-TURN Welding Fittings and Flanges. Call your nearby TUBE TURNS' Distributor . . . you'll find one in every principal city.

Be sure you see the double "tt"

TUBE TURNS, INC. LOUISVILLE 1, KENTUCKY

DISTRICT OFFICES: New York · Philadelphia · Pittsburgh · Chicago · Houston · Tulsa · San Francisco · Los Angeles · Denver · Atlanta

Subsidiaries: TUBE TURNS OF CANADA LIMITED, CHATHAM, ONTARIO • PENNSYLVANIA FORGE CORPORATION, PHILADELPHIA, PA.

ENGINEERING SERVICE

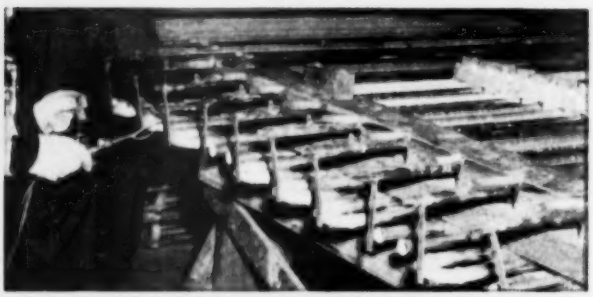
TUBE TURNS' *Engineering Service* HELPS DEVELOP NEW PIPING TECHNIQUE

D. R. Cheyney, of TUBE TURNS' Engineering Service Division, has had wide experience in alloy and non-ferrous applications.

THIS STORY of how a large processor saved $50,000 and conserved scarce copper with a new approach to a piping application shows why TUBE TURNS, INC. is so highly regarded as an authority on piping engineering.

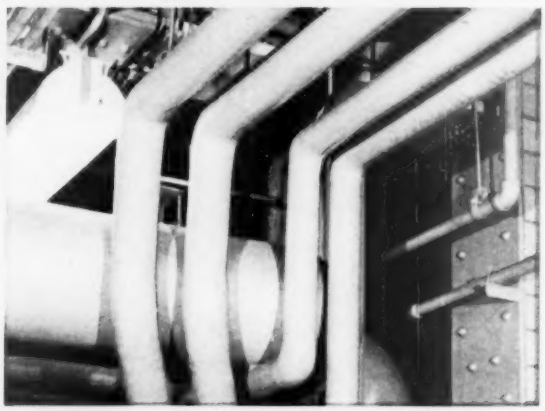
The problem involved the retubing of seven cooling units, formerly fabricated from copper tubing and fittings. Aluminum was considered as a replacement; however, there were no satisfactory methods for welding thin-walled aluminum tubing to welding fittings. TUBE TURNS' Engineering Service Division, working with Alcoa, came up with the solution. A new brazing technique was developed, and special TUBE-TURN Welding Returns, and TUBE-TURN Welding Elbows were supplied.

TUBE TURNS' Engineering Service is ready to help *you* in such special applications.



TUBE-TURN aluminum long-radius Welding Returns being brazed to aluminum tubing, in fabrication of cooling coils.

SPEEDS FABRICATION—TUBE-TURN Welding Fittings have won a reputation for dimensional accuracy that pays off in fast, easy alignment and fabrication. Time often is saved by welding assemblies in the shop, quickly tying them into the job.



SPACE SAVER—Welded piping makes a compact, neat installation—and requires no maintenance. Streamlined, its insulation is more easily applied.

Want Dimension Data?

TUBE TURNS, Inc. has compiled a handy folder of charts covering dimensions and weights of TUBE-TURN Welding Fittings and Flanges. If you'd like a free copy just send this coupon.

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224 East Broadway, Louisville 1, Kentucky

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TUBE TURNS, INC.

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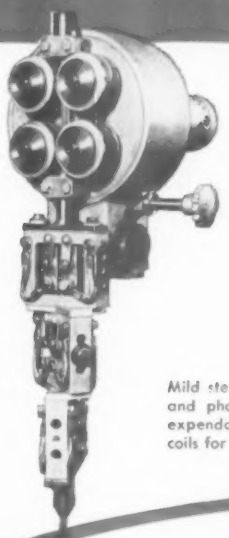
Every Welding Need

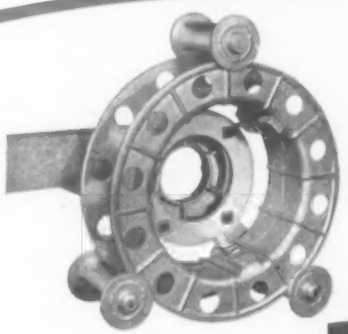


The Reid-Avery type 4R automatic head and control originally designed for Raco composite type A, may be used with equal success for lightly coated open arc or for submerged arc welding.

Raco composite type A heavy coated automatic (open arc) electrodes, a "Reid-Avery" first, can be furnished in all mild steel, low alloy high tensile, low hydrogen, hard surfacing and stainless steel grades.

Mild steel, alloy steel, stainless steel, aluminum and phosphor bronze wire are available on expendable wooden spools or in layer wound coils for gas shielded arc welding.

The Raco "free wheeling" reels are especially designed for high speed automatic machines. The ball bearing trunnions enclose the coil so there is no over-run or loose strands and larger coils can be used. Changing coils is a matter of only a few seconds and no tools are required. Available in 12, 14, 25 and 36 inch sizes, for any weight from 50 to 200 lbs.



The Raco coils of wire for submerged arc welding have long been known for their uniform high quality and convenient, easy to handle package. Special attention is paid to the accurate weight, lay and temper of the wire so that the wire will accurately follow a seam. Available in mild steel, alloy steel and stainless steel.

Since 1919 Reid-Avery Company has specialized in the manufacture of all types of welding electrodes and wire. The large modern plant in Baltimore is equipped for wire drawing, annealing, pickling, coating, cutting, winding and packaging. Every phase of welding electrode and wire production is completely controlled from start to finish. You can be assured of uniform high quality and the best possible deliveries.

We also manufacture a complete line of manual electrodes in the following grades:
Raco Mild Steel, Raco Low Alloy High Tensile, Racocast for nonmachinable welds on cast iron, Raco Feral for welding aluminized sheets, Raco Low Hydrogen, Raco Hard Surfacing, Racolloy Stainless, Racolloy Nickel and Nickel 60 for machinable welds on cast iron.

The REID-AVERY COMPANY
INCORPORATED
DUNDALK • BALTIMORE 22 • MARYLAND
SINCE 1919 PRODUCERS OF ARC WELDING ELECTRODES AND WELDING RODS

NEW LITERATURE

Stainless Steel Chart

Application chart for stainless, alloy, and nonferrous electrodes.

Weldwire Co., Inc., Philadelphia 25, Pa.

Pressure Vessel Manual

Manual for the Design of Ferrous and Non-Ferrous Pressure Vessels and Tanks. By Karl O. Siemon. Fourth revised edition. XVIII plus 308 pages. 5½ by 8½. Edwards Brothers, Inc., Ann Arbor, Mich. Price, $3.85.

Sight Feed Literature

Three new pieces of literature describing Sight Feed Welding Equipment are now available on request from the Sight Feed Generator Co., W. Alexandria, Ohio. Catalog Form AT-325 is a new bulletin describing Sight Feed Model A-Twin Acetylene Generators. Catalog Form RS-329 is a new release on Rexarc Automatic Welders and Positioners. A third piece of literature is institutional in nature and captioned "A Picture Story of the Sight Feed Generator Company."

Resistance Welding Bulletin

Sciaky Bros., 4915 W. 67th St., Chicago, Ill., *Bulletin No. 307-10*, covering the Sciaky rotating upper Stitch Welding Head which fits any electric resistance welder, explains how it produces gastight seams of overlapping spot welds to Government and Aircraft Specifications, for circular flanges and access holes, spuds and flanges to large panels, assembling parts with depressed circular flanges. Rotates 360 deg, radius 1 to 3 in., indexing from 0 to 9 deg.

Aluminum Electrodes

Coated aluminum electrodes 2S and 43S grades manufactured by the extrusion process. The coating is nonhydroscopic. The electrode is used on direct current reversed polarity and operates with a stable and quiet arc. Easy arc striking, easy slag removal and nice bead appearance are some of the enviable characteristics of this electrode. Data sheet on request. Weldwire Co., Inc., Philadelphia 25, Pa.

Welding Aids

Key production and maintenance men, metallurgists and others interested in welding methods will find a wealth of technical information on the welding of stainless, low-alloy, high-tensile and nonferrous metals in a booklet just published by Arcos Corp., Philadelphia, Pa.

This 18-page booklet is an index and guide to a series of bulletins, charts and articles prepared as "working tools" to facilitate welding and aid those responsible for plant welding practices to attain consistent quality results.

The following technical information is listed as available: (1) Application chart, giving descriptive information about 56 different electrodes; (2) data sheets, giving complete information on specific electrodes; (3) electrode selector folder, containing basic clues to the selection of the right electrode for welding; (4) chart of electrodes recommended for salvage and fabrication welding of alloy castings; (5) booklet on "The ABC"s of Welding High Tensile Steels"; (6) selector chart for welding high-strength, low-alloy steels; (7) selector chart for meeting Army, Navy and AMS specifications; (8) technical guides on specific metallurgical information; (9) chart on stainless cut and coiled wire to help in the selection of the proper stainless wire for semiautomatic and automatic welding.

The booklet or any technical information listed therein may be obtained by writing Arcos Corp., 1500 S. 50th St., Philadelphia 43, Pa.

Bronze Welding

Chemical and physical properties of bronze welding alloys produced by Titan Metal Manufacturing Co., of Bellefonte, Pa., are outlined and discussed in a new 6 page folder just issued by Titan.

All latest ASTM, AWS, Federal and Navy specifications which Titan bronze welding rods will meet are shown, as well as recommended uses and applications for specific Titan alloys.

The new folder points out Titan's rigid laboratory control methods—namely, the Double Deoxidation Process—which promote uniformity of mixtures, increase ductility, sound, dense deposits and reduced fuming in Titan bronze welding rods.

The folder can be obtained free by writing to Titan Metal Manufacturing Co., Bellefonte, Pa.

Stainless Steel

The extra low-carbon grades of stainless steel are fully explained in a booklet just published by Armco Steel Corp. The grades are 18–8 ELC (Type 304 L) and 18–12 Mo ELC (Type 316 L).

Some of the subjects covered are: Why carbon causes corrosion; how these special steels conserve scarce alloys; no need for a carbide dissolving anneal; clean steel—fine surface; ELC stainless steels meet the Huey accelerated corrosion test; and how to weld them. The booklet is well illustrated and includes tables on chemical analysis and typical mechanical properties.

The ELC stainless steels were developed by Armco to solve the problem of carbide precipitation alongside weld areas with attending intergranular corrosion. Before that, the only solution was to use columbium-tantalum or titanium grades of stainless. The booklet points out that the ELC grades should not be used for welded equipment exposed in service to temperatures above the sensitizing temperature of 800° F.

Basic Welding Principles

Basic Welding Principles, by Emanuele Stieri, is for the beginner or the expert a new and authoritative "how-to" book with up-to-the-minute instruction in all types of welding procedures. This book presents in a simple-easy-to-follow manner the latest developments in industry and follows the recommendations of the American Welding Society.

Self-Teaching Features

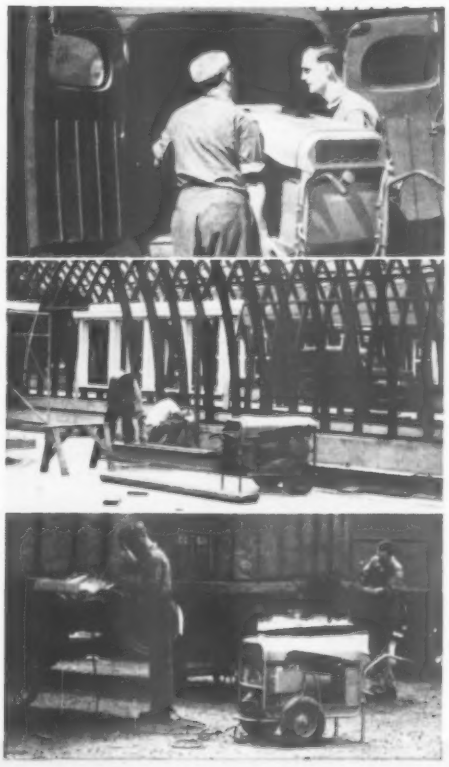
For each procedure, Mr. Stieri provides progressive practice exercises and detailed descriptions of tools. Over 650 illustrations clearly illustrate all points. Each chapter is summarized by a rapid review. For the complete volume a glossary defines all welding terms.

Approved and Tested Material

The author has written over 25 handbooks and books specializing in technical and mathematical subjects, and in preparing *Basic Welding Principles* he has applied all the proved techniques learned from his own experiences in industry and the classroom. He has kept the illustrations and exercises closely and clearly related to the written material. Contents and presentation are thoroughly checked by authoritative industrial and government agencies.

MORE WELDING AT LOWER COST

with Sureweld® Portable D-C Arc Welder



The Sureweld Portable Gas-Driven D-C Arc Welder is truly an amazing welder. Amazing because it is so small and light and portable. Amazing because it can get in where other welders cannot go. Amazing because you can do far more jobs *faster* with it than any other welder of its capacity.

One man can move it. Two men can lift it. Any auto, truck or station wagon can stow it. On the job it produces welding power at once and it handles 85-90% of all on-the-job welding. Most amazing of all, it saves so much, it repays its cost several times a year.

On multi-story building the Sureweld Portable moves easily from floor to floor with the operator—always within standard cable length of the work. No extra cable to buy. No power wasted because of excessive cable length. No hoisting of heavy cable from floor to floor.

In pipeline operations, the operator moves it as his work progresses—and thus his work progresses *fast!* In plant repairs, the Sureweld Portable is on the job in a jiffy and through with the job—in a jiffy. No shutdown of plant processes in order to tie a motor-generator set into a power line.

In these and many other ways Sureweld Portable increases production and saves its cost over and over again. Its price to you may cause you to revise your budget considerably. Users say they don't know how they got along without this most useful and economical piece of equipment.

Let us demonstrate the Sureweld Portable—any place you say. No cost or obligation. Use the coupon below or contact your nearest NCG branch or NCG authorized dealer.

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☐ Please rush Illustrated Bulletin NH-121 containing full details of the SUREWELD Gas-Driven D-C Arc Welder.

☐ You may arrange, at no obligation to me, a demonstration of the Sureweld.

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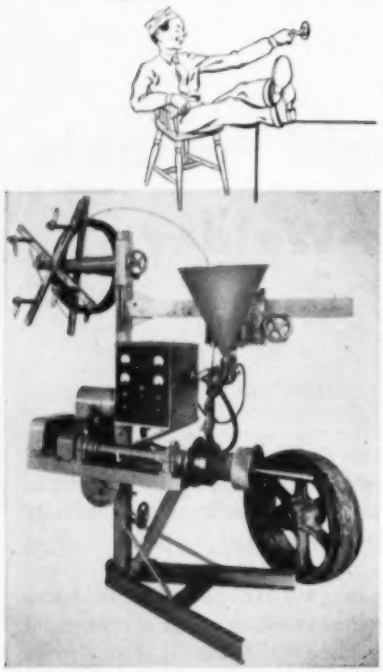
WELDING THAT IS

Really Automatic



Rebuilding rollers, idlers, crusher rolls and other circular shapes is fast and simple—with a Rexarc Automatic Welder and Positioner.

Metal is deposited at a fast rate with complete control over low arc voltage and amperage, minimizing stress and dilution of the parent metal. High frequency starting and stabilization assures a steady arc. Welding can be lineal or cross-bead, continuous or in sequence.

Welding on tractor rails and other longitudinal surfaces is accomplished easily by transferring the welding head and controls to a flat-bed positioner. All types of positioners for special applications engineered upon request.

REXARC
AUTOMATIC WELDERS
AND POSITIONERS

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THE SIGHT FEED GENERATOR CO.
57 EAST THIRD STREET
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Flexible Organization

For the greatest possible flexibility, Stieri knows how to arrange his material. Among the special devices he uses are: (1) Short teaching units with bold subheads; (2) two separate parts of the book: Part One on Oxy-Acetylene Welding and Cutting and Part Two on Electric Arc Welding; (3) "independent" chapters—each one is a distinct unit.

220 pages 8½ x 11. Price, $5.75. Prentice-Hall, Inc., 70 Fifth Ave., New York 11, N. Y.

Simple Blue Print Reading with Special Reference to Welding and Welding Symbols

A new, enlarged edition of 207 pages with over 200 illustrations; step-by-step explanation of how to read blueprints; complete discussion of welding symbols and where they are used; examples illustrated with drawings and photographs to help practice in visualizing prints; 6-x 9-in. size, stiff board cover with gold embossed simulated leather; price $1.00, delivered in USA, $1.50 elsewhere. Publisher, Lincoln Electric Co., Cleveland 17, Ohio.

The fourth edition of *Simple Blue Print Reading With Special Reference to Welding and Welding Symbols* has been announced by The Lincoln Electric Co., publishers. Over 100,000 copies of the book have been sold. The new fourth edition contains new information, more drawings and photographs than previous editions. All symbols and other data have been revised to bring them up to the latest standards.

This is a new and enlarged edition of a book for welders and others engaged in the fabrication of machinery. It is intended as a guide to a clear understanding of blueprints and how to use them in mechanical fabrication and construction. Special attention is given to the use of welding symbols.

The book makes a simplified approach to mastering the reading of blueprints. Using a simple welded base as a study object an explanation is made in step-by-step fashion of how the "sign language" of blueprints is used to transmit information. Large clear drawings are used to illustrate the explanation. After basic principles are explained, welding symbols and their use are fully described. Examples of where and how they are used are given in each case. To practice visualizing drawings numerous blueprints taken from actual shops are reproduced, followed by photographs of the objects as they are made.

The book explains subjects such as perspective drawing, isometric drawing, sight projection, center plane lines, dimensions, scales, sections, explanatory views, development of weld symbols, types of welds and gives questions and answers on subjects.

Engineering Manufacturing Methods

Written by Gilbert S. Schaller, Professor of Mechanical Engineering, University of Washington, this book is an extremely well-rounded presentation of current engineering manufacturing, and integrates manufacturing methods into the engineering educational program through use and correlation of engineering design, material and production standards, and codes in discussions. Manufacturing methods are presented as a vital part of engineering manufacture, not merely as an isolated subject.

With an excellent use of an engineering approach, the presentation is based on fundamentals and offers a comprehensive survey of the field. Included in this treatment is an extensive discussion of economic aspects of engineering manufacture, showing the importance of modern manufacturing thinking where costs predominate, and the availability of alternate methods in solutions of given problems.

All major aspects of engineering manufacture are presented—founding, machining, welding, hot and cold shaping, thermal treatment, and engineering materials—as well as a special emphasis on the latest technological developments.

Going further than the usual treatment of iron and steel materials, this text covers light metals, plastics, and copper-base alloys as well. Besides giving basic information on casting design, it treats new developments in plastic patterns.

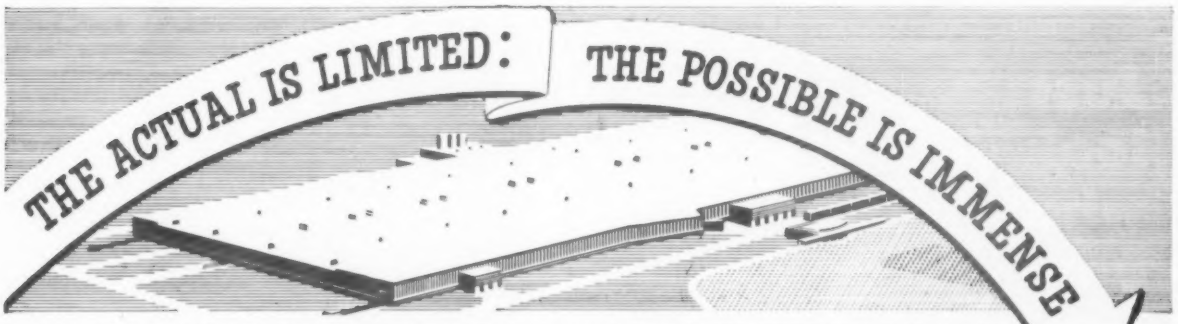
In an otherwise fundamental consideration of foundry sands, Olvine is included for the first time. The author introduces his original work, including frozen molds, and also offers information on shell molding.

Grouped ideally from a production point of view, automatic lathes, chucking, and screwing machines are given special treatment. The machining section includes developments from Switzerland, France, England and Scotland in order to bring the student complete information on modern methods.

Another first is the presentation of transfer and special machines, significant today through their increasing use in mass production industries.

Because of the author's excellent background in the field, the section on welding is particularly outstanding. It treats every type of welding and discusses the potentialities of each, and includes references to welding codes and engineering standards.

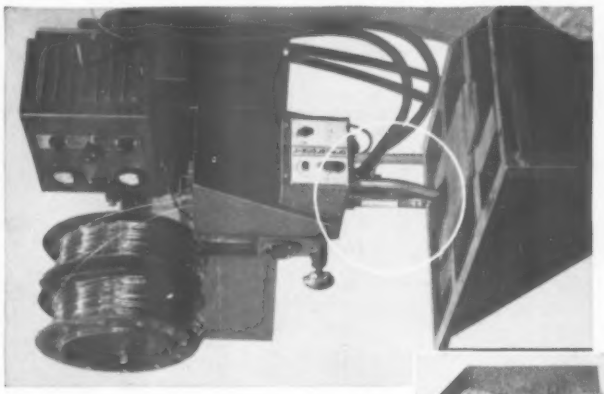
This book is, then, modern, complete, authoritative, and fundamental, and an excellent text for the standard course in

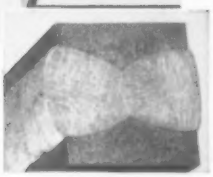


NEW LINCOLN PLANT CREATED BY INCENTIVE-INSPIRED CO-ACTION IN DEVELOPING POSSIBILITIES IN PRODUCT

© LE Co. 1953

"TWINARC'S" FASTER, LOWER COST WELDING BOOSTS SHOP EFFICIENCY





IT is now possible to realize savings up to 35% in the cost of automatic welding with Lincoln's new "TWINARC". Welds have deeper penetration, greater uniformity . . . and are produced at *speeds 50% higher* than possible with single electrode automatic welding.

Reports from code welding fabricators indicate quality superior to conventional automatic processes.

With "TWINARC", welding currents up to 1200 amps are concentrated on two small diameter electrodes (Fig. 1). These electrodes can be set in line with the work for tandem welding to attain maximum penetration at high speed. For welding thin material or assemblies with poor fitup the "TWINARC" head may be rotated in any position to 90 degrees across the joint to spread the arc, reducing the danger of burning through.

"TWINARC" welding is only one of many new Lincoln developments designed to cut your costs. Have your representative survey your needs and recommend latest Lincoln techniques to speed welding, to simplify your operations and save money.

Fig. 2. Automatic Lincolnweld LAF-2 *with new "TWINARC" attachment. "TWINARC" replaces original single electrode jaws. Operates with same single controls. Inset shows butt weld in 1-½" plate with single pass on each side with "TWINARC". Welding speed is 38% faster than possible with single electrode.*

INCREASES WELDING SPEEDS 50% AND HIGHER! TO CUT YOUR COSTS

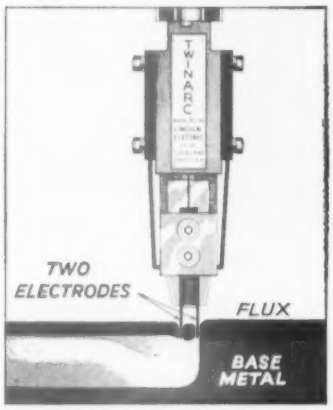


Fig. 1. New Lincoln "TWINARC"... *feeds two continuous electrodes simultaneously for faster, more efficient "hidden arc" welding in granular flux.*

Results... utilizes currents up to 1200 amps, produces deeper penetration, higher quality welds, at lower cost.

HANDLES A WIDER RANGE OF WORK

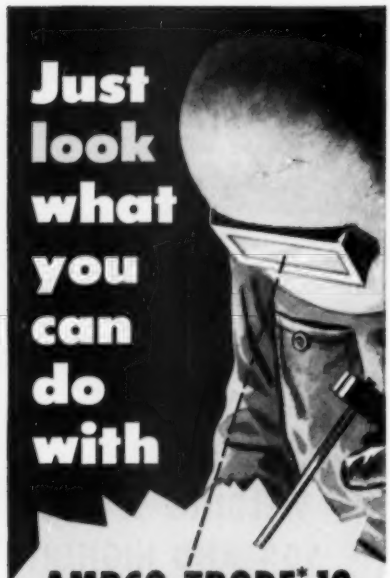
ANOTHER LINCOLN FIRST

GET THE FACTS — *Bulletin on "TWINARC" welding giving latest speeds and procedures is available by writing on your letterhead to Dept. 1905.*

THE LINCOLN ELECTRIC COMPANY

CLEVELAND 17, OHIO

THE WORLD'S LARGEST MANUFACTURER OF ARC WELDING EQUIPMENT



AMPCO-TRODE* 10
Bronze Electrodes

See us at the Welding Show, Shamrock Hotel, Houston, Texas, June 16-19, Booths 126-127

Weld Cast Iron
Weld Galvanized Iron
Weld Dissimilar Metals
Make Wear-Resistant Overlays
Make Corrosion-Resistant Welds
etc.

Yes, you can do a lot with Ampco-Trode 10. That's why we call this covered aluminum bronze electrode a general purpose rod.

When making overlays or when bronze-welding ferrous metal, we recommend medium arcs and weave beads. Amperage range is wide, because it welds a wide variety of metals. Use low side of amperage range for joining iron-base metals . . . the middle of the range for bronzes . . . the high side of the range when welding bearing copper base alloys.

The versatile utility of Ampco-Trode 10 keeps costs down, so it pays to have a supply on hand. If you want additional information call your Ampco distributor or write us.

W-118

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IT'S PRODUCTION-WISE TO AMPCO-IZE!

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manufacturing processes required of the mechanical engineering student.

613 pp. Price, $7.00. McGraw-Hill Book Co., Inc., 330 W. 42nd St., New York 36, N. Y.

Occupational Safety Service Guide

The National Safety Council's new Occupational Safety Service Guide provides company safety directors with a complete catalog of the many and varied accident prevention aids available from the Council.

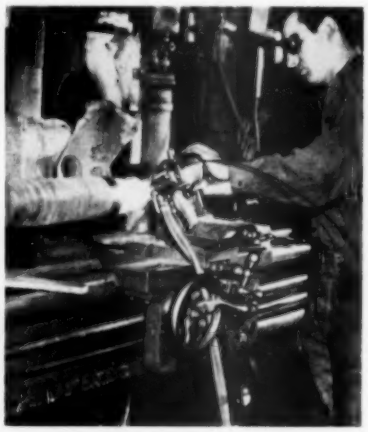
For the safety man, the 52-page guide offers the Council's periodicals, newsletters and a complete library of technical and administrative publications covering all phases of occupational accident prevention. Information on the subjects covered in the basic and advanced courses of the Council's Safety Training Institute also is included.

Copies of Service Guide 2.1 can be obtained without cost by writing the National Safety Council, 425 N. Michigan Ave., Chicago 11, Ill.

20-Min Salvage Jobs

A leading manufacturer of heavy road-building equipment uses metallizing for the salvage of parts accidentally mismachined in their production shop. Most of this work is done on the bearing and seal-fit portions of front-stub axles used on their earth-moving equipment. These axles varying in size and shape are valued, after manufacture, at between $75 and $130.

Typical application is the salvage of stub axles—of 5-in. bar stock, 30 in. long—accidentally machined undersize at one of the bearing fits. The part was set up in a lathe, cleaned with emery cloth and then sprayed with Sprabond Wire for about 10 min to bring the undersized area to the required dimension, with allowance for finishing.



A number of these axles have been in service for 18 months, withstanding the toughest kind of service. There has not been a single report of equipment trouble due to the metallized parts. As a matter of fact, the Engineering Department of this large manufacturer indicates that the hard, oil-bearing, metallized surface should provide a longer service life than an unmetallized part.

Other metallizing applications are also described and illustrated in the current issue of *Metco News*. Some of these include salvage of worn spindles, cast-iron rolls and truck anchor pins. Write for a copy of *Metco News*, 6, No. 7 to Metallizing Engineering Co., Inc., 38-14 30th St., Long Island City 1, N. Y.

The Welding Austenitic Corrosion-Heat-Resisting Steels

This book was compiled by the British Welding Research Assn. in collaboration with British Chemical Plant Manufacturers' Assn., The British Electrical and Allied Manufacturers' Assn., Council of British Manufacturers of Petroleum Equipment, The Society of British Aircraft Constructors Ltd., Stainless Steel Fabricators' Assn. of Great Britain and The Stainless Steel Manufacturers' Assn.

Each chapter has been prepared by recognized experts and pioneers in the particular welding process reviewed. It was written with the practical problems of the design office and the workshop in mind, with a sound background of the technical considerations involved. It includes 100 illustrations and many tables giving recommended techniques, etc.

The book contains chapters on the following: Metallurgical Considerations; Control of Distortion and Prevention of Cracking; Welding Methods, including Metal-Arc, Submerged-Arc, Argon-Arc, Oxy-Acetylene, Atomic-Hydrogen, Carbon Arc, Resistance-Welding Processes, Oxy-Acetylene Pressure Welding; Cutting Methods; Heat Treatment After Welding; Surface Finishing After Welding; Inspection and Testing, and Welders' Tests; Welding 18-8 steels to other metals, Welding of Stainless-Clad Steels, and Austenitic Chromium-Nickel Heat-Resisting Steels. Appendices on proprietary makes of Cr-Ni steels, Standard Specifications, etc. Selected Bibliography and comprehensive index.

8½ x 5½ in., 224 pp. Price, $4.00 postpaid. Publications Department, British Welding Research Assn., 29 Park Crescent, London, W. 1., England.

Stainless Steel Electrodes

Alloy Rods Co., York, Pa., manufacturer of stainless steel alloy arc welding electrodes, has just released a 20-page catalog in color on its complete line of Arcaloy Stainless Steel Electrodes. The catalog includes explanation of the two basic types offered—Lime coating for all-position welding with d-c reverse polarity, and a-c, d-c for welding of chrome-nickel steels with all types of a-c or d-c welding equipment—individual descriptions of the 23 regular analyses and special analyses of Arcaloy electrodes, weld metal properties,

REXWELD extends SERVICE LIFE of Hartig extruder feed screws by 400%

Here is a typical case of how REXWELD Hard Surfacing Rods are used to extend tool and product life . . . to provide a better, crack and porosity free surface that wears longer.

One of the most important parts of the plastic extrusion machines made by the Hartig Engine and Machine Company is the *feed screw*. This part propels heated plastic through an extrusion die under great pressures, and at rates as high as 2000 pounds per hour. Because the slightest amount of wear on the screw is so critical — on some jobs more than 0.010″ means replacement — Hartig hardfaces them with REXWELD C by the oxyacetylene process.

The Hartig people have found that REXWELD C extends the life of the screws 400% over unsurfaced screws . . . provides a surface that resists abrasion and corrosion . . . and gives them a dense facing free from surface imperfections — an important factor from the standpoint of product contamination.

Next time you have a hard surfacing job which requires the best in service life and ease of application, ask for REXWELD Hard Surfacing Rods. They are available in many different grades and sizes, and in electrodes bearing the special REXWELD low hydrogen coating.

CRUCIBLE

53 years of Fine steelmaking

REXWELD HARD SURFACING ROD

CRUCIBLE STEEL COMPANY OF AMERICA, GENERAL SALES OFFICES, OLIVER BUILDING, PITTSBURGH, PA.

REZISTAL STAINLESS • REX HIGH SPEED • TOOL • ALLOY • MACHINERY • SPECIAL PURPOSE STEELS

ACCO products for Stainless Steel WELDING

How Do You Buy It?

• No matter how you buy stainless steel welding wire—on reels, in coils, or packages of rods or electrodes—PAGE can supply you in a variety of analyses.

AC-DC Electrodes—Gas Welding Rods

Stable burning even at lower heats. Slag is clean and easily removed. Coating resists cracking right down to short stubs. Your choice from a complete line for every type of stainless welding.

for Inert Gas Welding

Six Page-Allegheny stainless grades in .035″, .045″, and .0625″ diameters. Precision thread-wound on 25-lb. non-returnable reels to fit popular arc welding machines.

for Submerged Arc Welding

PAGE stainless in wire diameters from 1/32″ to 5/16″, plain or copper coated. In layer-wound coils, 22″ or 24″ mill coils, or 200-lb. returnable steel reels.

Write our Monessen, Pennsylvania office for literature and prices

ACCO

SEE US AT BOOTH 146
WELDING EXPOSITION - HOUSTON

PAGE STEEL AND WIRE DIVISION
AMERICAN CHAIN & CABLE

Monessen, Pa., Atlanta, Chicago, Denver, Detroit, Los Angeles, New York, Philadelphia, Portland, San Francisco, Bridgeport, Conn.

PAGE Welding Electrodes Rods Wire

welding procedures, electrode analysis and color charts, current ranges, and AISI type numbers. Copies of the new catalog may be secured by writing Alloy Rods Co., York, Pa., and asking for Bulletin AR53-16.

ASTM Specifications for Steel Piping Materials

The December 1952 edition of this compilation, sponsored by ASTM Committee A-1 on Steel, contains in their latest approved form the 56 widely used ASTM specifications for carbon-steel and alloy-steel pipe and tubing, including stainless.

Materials covered include: pipe used to convey liquids, vapors and gases at normal and elevated temperatures; boiler, superheater, and miscellaneous tubes; still tubes for refinery service; heat-exchanger and condenser tubes. To make the volume more complete there are also included specifications for the following materials used in pipe and related installations: castings; forgings, and welding fittings; bolts and nuts. The ASTM standard classification of austenite grain size in steels (E19) with two sets of charts; also the American Standards covering wrought steel and wrought iron pipe (B36.10) and stainless steel pipe (B36.19) are a part of the book.

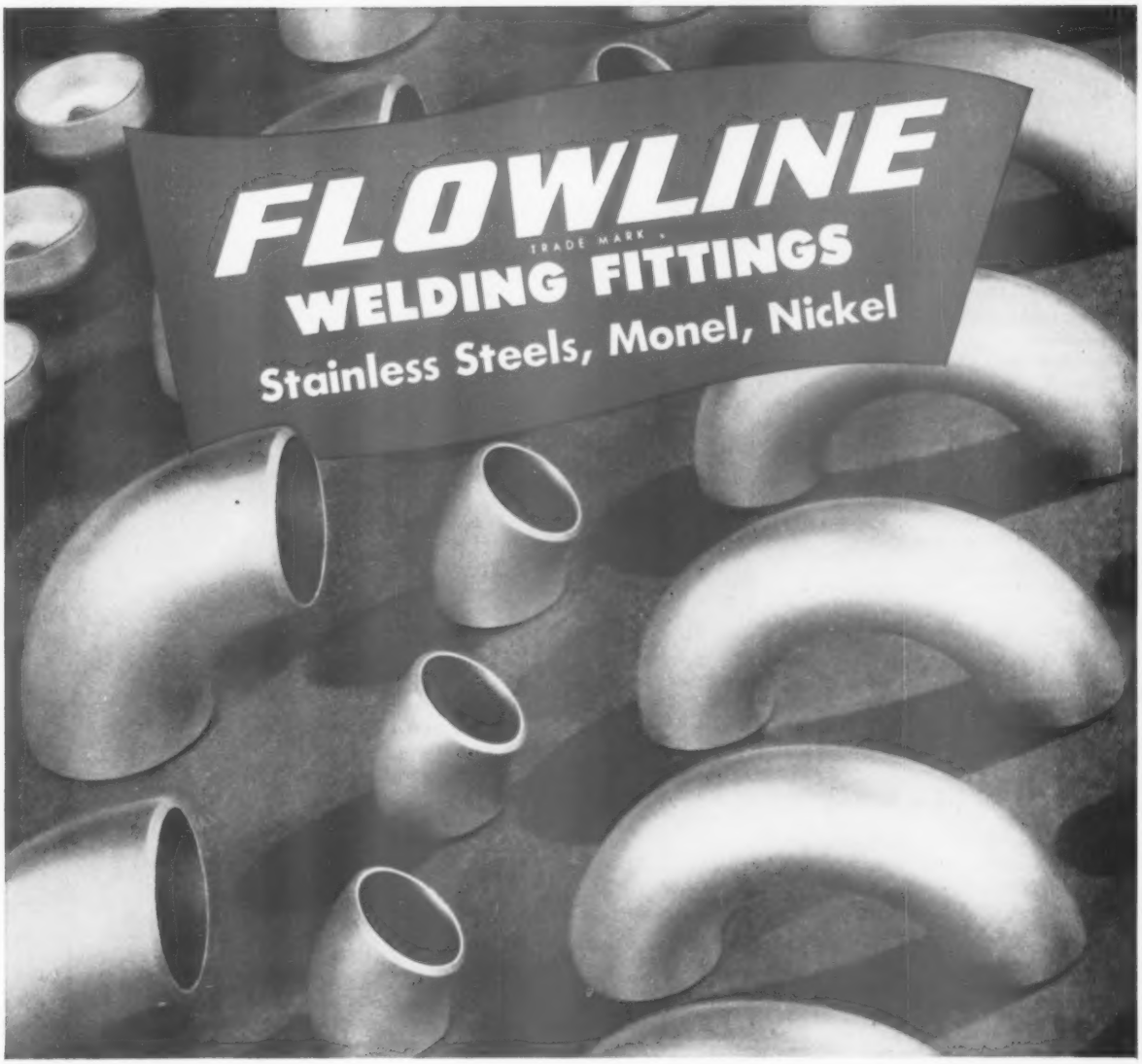
New specifications cover: quenched and tempered alloy steel bolts and studs with suitable nuts; electric-fusion-welded austenitic chromium-nickel alloy steel pipe for high-temperature service; iron-chromium and iron-chromium-nickel alloy tubular centrifugal castings for general applications.

Sixteen Emergency Alternate Provisions applying to specifications in this compilation are printed in the pink section at the back of the book. (These Emergency Alternate Provisions are issued by the American Society for Testing Materials in accordance with a special procedure in the interest of expediting procurement or conservation of materials during the period of National Emergency. They are intended for use where they may be considered by the purchaser of the material as a permissible alternate for the specific application or use desired.)

The grade designations in all tubular specifications as well as specifications covering forgings used in conjunction with pipe at high temperature have been reviewed and correlated.

These specifications are in widespread use and this book is of distinct service to those concerned with pressure piping, power generating, the petroleum field, distribution of water, gas, oil and the like, and to individuals in every industry where these materials are so important.

Copies of this 394-page publication, heavy paper cover, can be obtained from Headquarters of the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa., at $3.75 each.



3000 Stock Items Made by Corrosion-Resistant Specialists

The makers of FLOWLINE Welding Fittings were the first to standardize, manufacture, and stock a complete line of welding fittings for corrosion piping. These fittings are handled by leading distributors throughout the country who are experts in corrosion piping problems.

The most economical and efficient corrosion-resistant piping system is obtained by using FLOWLINE Fittings. Any conceivable layout can be constructed with them simply by straight cutting of pipe to desired lengths and plain butt welding. The advantages include minimum initial cost and faster fabrication of a compact, light weight and strong system which is permanently leak-proof and has best flow characteristics.

FLOWLINE Welding Fittings — ells, tees, stub ends, reducers, and caps — are normally stocked at strategic points in Schedules 10, 40, and 80 (Schedule 5 also available) — sizes ½″ through 12″ — in stainless types 304, 316, and 347; Monel and Nickel. They are annealed, cleaned bright — stainless fittings are passivated — and marked with type of metal, heat number, size, schedule, and wall thickness.

WELDING FITTINGS CORP.

NEW CASTLE, PENNSYLVANIA

World's Largest Manufacturer of Stainless Welding Fittings

PERSONNEL

Clevenger Named Sales Manager

The appointment of James O. Clevenger as sales manager of general industrial products of the Westinghouse Electric Corp. has been announced by W. W. Sproul, vice-president.

A native of North Carolina, Mr. Clevenger joined Westinghouse in 1927 and was a member of the Syracuse, N. Y., sales staff from 1929 to 1931. He transferred to the Pittsburgh construction and communication section of the company in 1935 and became section manager in 1939. He became manager of agency and specialty sales for the Southeastern District in Atlanta, Ga., in 1947, and was located there until his appointment as manager of the welding department at Buffalo in November 1949.

In his new capacity, Mr. Clevenger will be located at company headquarters in Pittsburgh, Pa.

Forty-Five Years of Service

In the spring of 1914 a young man at Ohio State University nervously waiting for an interview with James F. Lincoln to apply for a job with the Lincoln Electric Co. quickly slipped his fraternity pin from his lapel. He was a fraternity brother of Mr. Lincoln and did not want their fraternity bond to influence the interview in any way.

That young man, A. F. Davis, is now Vice-President and Secretary of The Lincoln Electric Co. and recently had occasion for remembering his first interview with Mr. Lincoln. He slipped another pin on the lapel of Lincoln. At the company's annual banquet, Davis presented to Lincoln a service pin in recognition of Lincoln's 45 years with the company, 39 of which have been as executive head of the company.

James F. Lincoln joined his brother, John C. Lincoln, in 1907. John had started the Lincoln company in 1895 making electric motors. James assumed executive management in 1914 and began to direct the company's interests into a field just then beginning to be heard of, electric arc welding. Mr. Lincoln has led the company to becoming the world's largest manufacturer of arc-welding equipment and has himself become famous throughout the entire industrial and business world for his enlightened ideas on business management.

Approximately 1000 company workers, their wives and friends gathered for the

company's annual banquet and dance, which was the occasion for the presentation of service pins. Pins in recognition for service of 10 years or more were given to 188 Lincoln workers. It was the largest group of service pins ever given by the company.

A. C. Brown, Jr., General Sales Manager

A. C. Brown, Jr., regional manager of the Air Reduction Sales Co., has been appointed general sales manager, it was announced by H.R. Salisbury, president. Mr. Brown, who has been located in Pittsburgh, will have his headquarters at 60 E. 42nd Street, New York, N. Y.

Joining Air Reduction in 1935, he served in various capacities including salesman and branch manager at Grand Rapids, Mich., and district manager at Cleveland, Ohio. In 1950 he was appointed manager of Air Reduction's Central Region with his office in Pittsburgh, Pa., a post he held until this promotion.

A graduate of Yale, Mr. Brown is a member of a prominent Cleveland family. His father, A. C. Brown, Sr., is president of the Cleveland Cliffs Iron Co.

J. H. Keeney, administrative assistant in Pittsburgh, succeeds Mr. Brown as regional manager.

J. H. Hart, Detroit district manager, succeeds Mr. Keeney. R. A. Jamieson, assistant sales manager, Detroit, succeeds Mr. Hart.

Air Reduction Sales Co., a division of Air Reduction Co., Inc., is a major producer of oxygen, acetylene and welding and cutting equipment.

Coughlin Manager of Arc-Welding Department

Appointment of J. P. Coughlin as manager of the Arc-Welding Department of the Westinghouse Electric Corp. has been announced by Tom Turner, vice-president.

Mr. Coughlin was graduated from the University of Missouri in 1939 and joined Westinghouse immediately thereafter. Subsequently, he served as welding sales engineer for the Southwestern District with headquarters in St. Louis. In 1942, he was commissioned in the Navy and served as officer in charge of welding construction at several large shipyards.

In 1945, Mr. Coughlin returned to Westinghouse as manager of welding products of the agency and specialty sales department, East Pittsburgh, and held this position until his appointment as manager of field sales for the welding department in 1949.

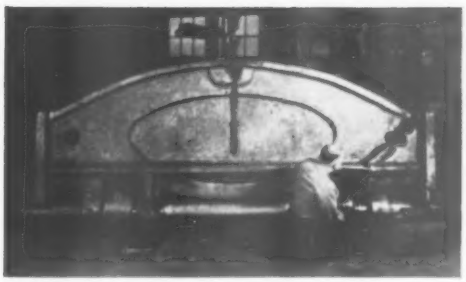
Alexander Gobus to Head New Philips Department

A new Non-Destructive Testing Department, headed by Alexander Gobus, has been established by North American Philips Co., Inc., to handle new research developments in the industrial X-ray field, it was announced recently.

One of the country's leading experts on industrial fluoroscopy and radiography and other forms of nondestructive testing, Mr. Gobus joined Philips on March 1st and has offices in the company's

THIS PRESS BRAKE weighs 122,000 pounds and its rated capacity is 400 tons. It is used for straightening armor plate measuring up to 12 feet wide, $3\frac{1}{8}$ inches thick and $16\frac{1}{2}$ feet long.

400-TON PRESS BRAKE DRAFTED FOR DEFENSE



V-GROOVE GRINDING COMPLETED, the two segments of the 5-foot x $12\frac{1}{2}$-foot crown are ready for braze welding with ANACONDA-997 (Low Fuming) Bronze Welding Rod. Body of the crown is $7\frac{1}{2}$ inches thick. The bottom flange measures 19 inches wide x $3\frac{1}{2}$ inches thick and the top flange is $12\frac{1}{2}$ inches wide x $3\frac{1}{2}$ inches thick.

HERE'S THE FINISHED JOB—which required 250 pounds of welding rod.

Ready to be scrapped because of a $2\frac{1}{2}$-foot diagonal fracture, the crown section of this press brake was saved by braze welding with ANACONDA Rod. A new crown would have cost thousands of dollars and taken several weeks' time for delivery. Remembering our slogan, "Don't Scrap It—Braze Weld It," the owners consulted Hebeler Welding Company, Buffalo, N. Y., who braze-welded the crown with ANACONDA-997 (Low Fuming) Bronze Welding Rod. In less than a week the press was ready for service—straightening armor plate.

There's a suitable ANACONDA Bronze Welding Rod for just about every type of welding job. Anaconda Publication B-13 contains suggested applications and procedures for production and repair welding with bronze rods. Write for it today—Address The American Brass Company, Waterbury 20, Connecticut. In Canada: Anaconda American Brass Ltd., New Toronto, Ontario.

62170

braze or weld with confidence

ANACONDA® ***welding rods***

Alexander Gobus

plant, 750 S. Fulton Ave., Mount Vernon, N. Y.

He was Vice-President, Chief Metallurgist and Director of Non-Destructive Testing, Sam Tour & Co., Inc., from 1943 to 1953. Prior to that, he held positions of responsibility with Lucius Pitkin, Inc., Interborough Rapid Transit Company of New York City, American Car and Foundry Co. and Doehler Die Casting Co.

Mr. Gobus is a recognized author and lecturer as well as a consultant on matters pertaining to all phases of nondestructive testing. He has held and still holds many important committee posts with various technical societies.

He is a member of the American Society for Metals, American Welding Society, American Institute of Mining & Metallurgical Engineers, American Industrial Hygiene Assn., American Society for Testing Materials, Society for Non-Destructive Testing and the Metals Science Club of New York.

He is now the American Welding Society Representative to the American Standards Assn. group charged with modernizing the present code for X-ray protection. Mr. Gobus is also a member of the Propeller Club of the U. S. (Port of New York), the Queens County (New York) Grand Jury Assn., the Marine Corps Fathers Assn. and the Huntington (Long Island) Anglers Club.

President Plummer Honored

At a special luncheon in Cleveland on April 11th the Board of Trustees of Case Institute of Technology presented a citation to Fred L. Plummer, Director of Engineering of the Hammond Iron Works, for "having distinguished the college and himself through outstanding achievement in his chosen field." Mr. Plummer is one of a small group of men chosen for this honor from the several thousand members of the classes graduated by Case during the 40-year period from 1894 to 1934.

The luncheon was part of the Case Diamond Jubilee Convocation which opened the celebration of the first 75 years of service by Case to Cleveland and to the Nation. The Convocation included four panel sessions in Severance Hall, home of the Cleveland Symphony Orchestra, and two evening sessions in Cleveland's Municipal Auditorium. Speakers at the evening sessions were Herbert Hoover, former President of the United States; Clarence Decature Howe, Minister of Trade and Commerce and of Defense Production of Canada; and Clifford F. Hood, President of U. S. Steel Corp. Speakers at the panel sessions included 22 others of the world's distinguished leaders in industry, science, government, education and religion. The general theme of the Convocation was "The Atomic Age—A Challenge to Free Men."

Mr. Plummer attended a formal dinner given by the Case Trustees for the speakers and honored guests at the Convocation.

OBITUARY

Eric R. Seabloom
First Vice-President, AWS

Eric R. Seabloom, First Vice-President of the American Welding Society and Supervisor of Field Engineering, Crane Company of Chicago, Ill., died suddenly at his home on Sunday evening, Feb. 22, 1953, at the age of 53 years.

Mr. Seabloom was born Oct. 16, 1899, in Vesteros, Sweden, and came to the United States in 1909. He attended the Lane Technical High School and the Illinois Institute of Technology. In 1917 he became associated with Crane Co. as a draftsman in the Product Engineering Department, later serving as an estimator and designer. In 1921 he was transferred to the company's Engineering Laboratories as a testing engineer and did development work on industrial products. From 1925 to 1935 he served as Research Engineer in charge of the Industrial Section of the Laboratories.

During this latter period his interest in welding grew and in 1932 he was given the position of Welding Engineer in addition to his other duties. The rapid growth of welding necessitated relinquishing other assignments to devote full time to welding and welding research. In 1939 he was appointed Supervising Engineer of the Engineering Laboratories to coordinate the activities of the many laboratory groups. Since 1948 he was Supervisor of Field Engineering. Welding continued as his major interest.

Mr. Seabloom was active in the American Welding Society for many years, serving as a Director-at-Large 1943 to 1946, Vice-Chairman 1941–42, Chairman of the Chicago Section 1942–43, Director of the Section 1943–46 and Second Vice-President 1951–52. He was a member of the AWS Committee on Awards, AWS-ASTM Committee on Filler Metals, WRC Advisory Committee on Public Utilities Welding Research and served on the Welding Handbook Committee, ASA Code for Pressure Piping, Technical Committee of the Pipe Fabrication Institute and other committees. Mr. Seabloom published many papers on welding and presented 93 talks, mostly on welding, before AWS local sections and other engineering groups.

His technical society affiliations, beside the American Welding Society, included the American Society for Metals, the American Petroleum Institute and the Society for Non-Destructive Testing.

Mr. Seabloom is survived by his wife, Florence, his mother, Hilma, and two sisters, Mrs. Corrine Gustafson and Mrs. Margaret Thiel.

Mrs. Catherine V. (Hickey) Hefferan

Catherine V. Hefferan, better known to her many friends in the AWS as Miss Catherine Hickey, died on March 20th after an illness of about a year.

Catherine Hickey joined the American Welding Society as a member of the staff in February 1922. She served for many years as secretary to Miss M. M. Kelly, National Secretary of the American Welding Society. She left in June, 1949 to become the wife of Dr. John Hefferan, chiropractor in New York City. For the last ten years of her connection with the Society she was general secretary and assistant to the Technical Secretary. In this capacity she served well and faithfully under W. Spraragen, L. M. Dalcher and S. A. Greenberg. Her cheerful nature and general willingness to be of service were appreciated by those coming in contact with her and particularly by the Technical Activities Committee.

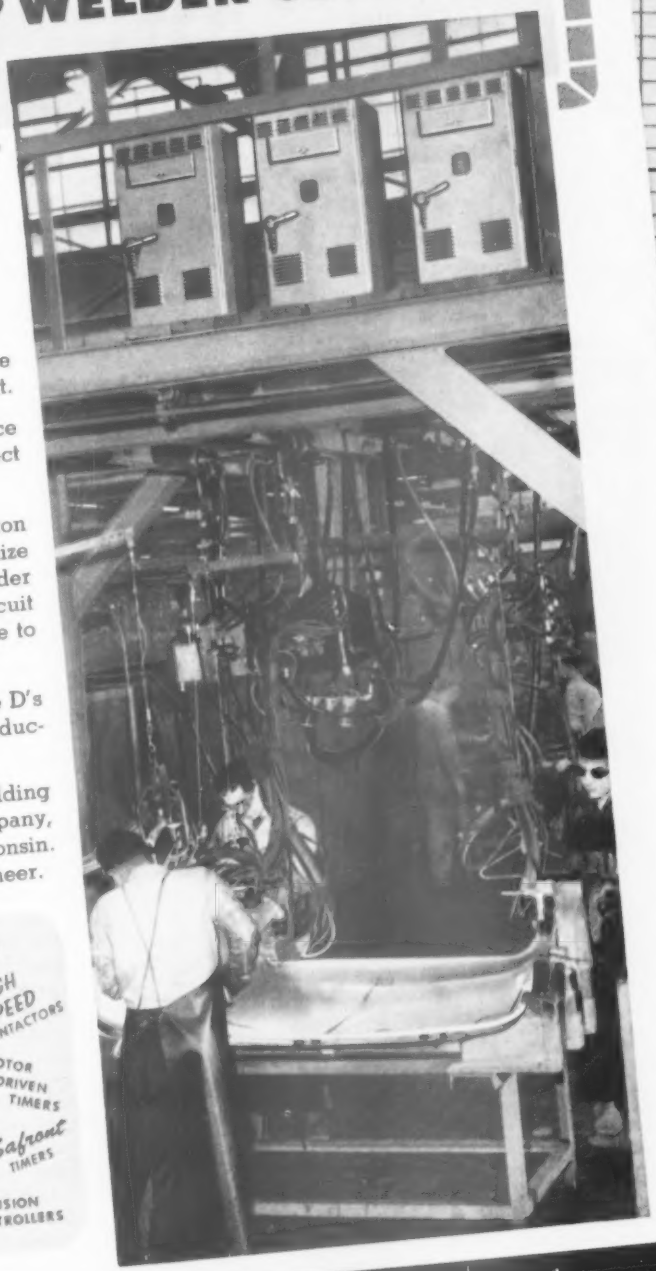
Milton M. Weist

Milton M. Weist, 55, manager of the Minneapolis district of Air Reduction Sales Co. since 1941, died on March 6th in Palm Beach, Fla., where he had been vacationing.

He was active in the Northwest Section of the Society and associated industries of Minneapolis and was a member of the Minneapolis Club.

Mr. Weist was with Air Reduction for over 35 years and served in various capacities including salesman, assistant sales manager and district manager of the Chicago district.

LOWER PRODUCTION COST WITH SQUARE D *Electronic* WELDER CONTROL



New Cleveland Automotive Plant Uses Square D Control on Gun Welders

• Square D control is paying off in three important ways in this new mass-production plant.

LESS INSTALLATION TIME was needed since the contactor, sequence-weld timer and disconnect are combined in one enclosure.

LESS MAINTENANCE because firing of ignitron tubes is synchronized with power line to minimize transients and reduce strain on cables and welder transformer windings. Fail-safe weld time circuit greatly reduces possibility of burning work due to control tube failure.

MORE CONSISTENT WELDS because Square D's lead-trail circuit feature insures full-cycle conduction and prevents transformer saturation.

• Can Square D help you do a better welding job? Write for Bulletin 8992. Square D Company, 4041 N. Richards Street, Milwaukee 12, Wisconsin. Or talk to your nearby Square D Field Engineer.

The BEST Resistance Welder Control?

There is no one type. Square D builds both magnetic and electronic controls of many types—each best suited to certain types of applications. Specify Square D, and be sure of getting the best for your job.

HIGH SPEED CONTACTORS

MOTOR DRIVEN TIMERS

Safgraf TIMERS

Electronic TIMERS & CONTACTORS

SYNCRO-BREAK CONTACTORS

SYNCHRONOUS-PRECISION COMBINATION CONTROLLERS

SQUARE D COMPANY

1903 • 50 YEARS OF DESIGN LEADERSHIP • 1953

NEW PRODUCTS

Eutectic Demonstrates Stone Cutting and Melting

A new, patented process for cutting and piercing stone, cement, concrete and refractory materials, trade named "DynArc," was demonstrated to editors March 20th at a luncheon given by the ChemoTec Division of Eutectic Welding Alloys Corp., Flushing, N. Y., at the Roosevelt Hotel, New York.

These characteristics represent the technically "impossible"; rock was pierced and the liquid stone poured out of the hole.

The DynaTrode creates its own arc. It requires no ground and it does not have to be struck upon metal. The operator has complete control at all times and he alone determines when and where the arc will start. This is not the only departure from the conventional. The arc, which will operate in mid-air as well as it will upon stone, resembles a flame in appearance. It has all the characteristics of a super torch flame from 5 to 8-in. in length.

Technically, DynaTrode is a self energizing arc rod (two rods are electrically insulated from each other with the arc forming at the end). The heavy coating, especially formulated to give the thermochemical interreaction with the arc stream to react with the nonmetallic material, is reduced more slowly than the core. This forms a crucible or tube of coating through which the tremendous energy is concentrated into a fine tip and its character has been changed by the disintegrating coating. The thermal ionization of the coating by the arc stream, combined with the concentration, produces the conditions necessary to pierce and melt the refractory material.

These are properties of formulation and electrical and thermal equilibrium which produce a predetermined thermochemical interreaction between the process of electrode disintegration and the components of the refractory material.

Wherever a d-c welding machine of 400 amp or more capacity is available, the DynArc process may be used. The multiplicity of equipment associated with high temperature and pneumatic cutting and drilling was conspicuously absent. No compressors, air lines, oxygen tanks, pneumatic drills, etc., are necessary. A conventional welding machine and a supply of DynaTrode rods were all the equipment required.

This opens up fields hitherto unexplored. A welding machine is readily available and its productive capacity is now extended to an incredible degree.

When equipment has to be installed the time-consuming drilling of holes in the concrete is eliminated. The DynaTrode will pierce the solid concrete in a matter of seconds, the manufacturer claims.

Pipes buried in masonry present a problem when they require attention. The problem is simplified with this versatile electrode. The masonry can be pierced with DynArc and the pipe exposed. Then, should the metal pipe require cutting or piercing, the metal-cutting electrode, CutTrode, can be exchanged for a DynaTrode and the whole operation carried out by the operator with a standard welding machine.

These are but a few of numberless applications of this universal industrial instrument. The portability and adaptability are distinctive features duplicated in no other product. The properties are all incorporated into one slender rod. The results obtained with this pencil-like rod, weighing but a few ounces, are only obtainable by conventional means when large quantities of heavy equipment are brought into operation.

For further specifications, technical data, etc., write ChemoTec Division, Eutectic Welding Alloys Corp., 40-40 172nd St., Flushing, New York, N. Y.

Hard-Facing Base Electrode

While there are a good many electrodes on the market which are variously recommended as suitable for general welding and buildup, many of these rods do not supply all the properties required for rebuilding of steel parts preparatory to a hard-facing overlay. It has frequently been found that failure of such overlays is directly traceable to movement or cold flowing of the underbase when subjected to heavy compression or impact. The underbase must have high tensile strength and rigidity to properly support the hard metal.

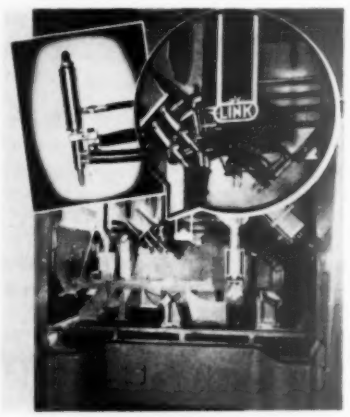
A new electrode recently marketed under the name Stoody Build-Up by Stoody Co., of Whittier, Calif., has been developed with the sole idea of providing the exact properties necessary in a material used for rebuilding carbon steel and alloy steel parts—sound deposits, high tensile strength, toughness and resistance to cold flowing. As an underbase it is generally recommended for such parts as drive sprockets, churn drills, shovel drive tumblers and house rolls, tractor rollers and idlers, tool joint shoulders and clutch jaws.

Stoody Build-Up is an extruded alloy-coated electrode designed to produce an alloy steel deposit of consistent medium hardness of 29–31 Rockwell C under normal conditions. Deposits are affected by heat treatment and will react to abnormal temperature ranges like any other alloy steel.

While Stoody Build-Up is not a hard-facing alloy and not intended for such applications, it has certain limited uses as a final overlay on equipment where impact is the principal wear factor—steel shafting, gears and tractor rails. Deposits are machinable with high speed tools.

Point Holder for Resistance Welding

Recently announced by Harry Day, Vice-President of Link Welder Corp., Detroit, was the development and production of a point holder applicable to standard types of transformer cables.



The Link electrode holder is reported to be of a unique collet-type design, applicable in gun mounting. The producers of this item claim that it has more stability than is found in conventional point holders when used with offset points. Applications of this holder indicate that its use in multiple-spot-welding machines effects appreciable reduction in maintenance costs.

The reported economy of the Link electrode holder is based on two-piece construction, permitting replacement of either contact plate, or shank, or the repair of either. Shanks are available in lengths to permit the use of one welding electrode length, regardless of relationship between cylinder and part. Another advantage stressed

The Greatest Advancement in D.C. Welding!

THE NEW A.O.Smith RECTIFIER

OUTPERFORMS ANY MOTOR GENERATOR SET MADE!

No moving parts to wear out. No brushes and bearings to replace. No commutator to corrode or turn down . . . maintenance expense practically eliminated.

Instant striking and smoother arc! There's no inductive time lag usually found in motor generator sets.

OUTPERFORMS ANY OTHER RECTIFIER MADE!

Eliminates stack failure. High-velocity, down-draft ventilation provides plenty of cooling air within the machine. There's no need for thermostatic protection, no interruptions because of current cut out! Even when short circuited while set at rated output, rectifier-stack temperature rise is held below critical levels!

Eliminates machine noise and current creep. No large magnetic forces develop to cause vibration or tear the machine apart, thanks to its moving-coil design. And positive air separation between primary and secondary coils guards against insulation failure which otherwise might put line voltage on welding leads.

If your jobs call for DC welding . . . you'll weld faster, better, at *less* cost with this new A. O. Smith D. C. rectifier welder—an entirely new concept in D. C. production welding!

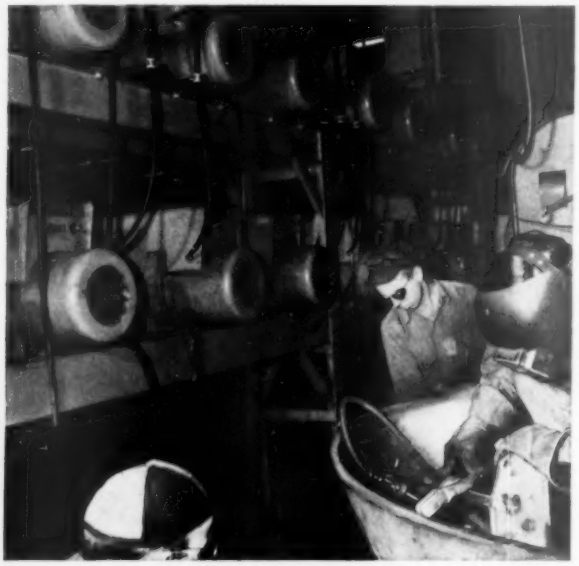
For complete information and name of nearest distributor or A. O. Smith representative, write:

A. O. SMITH CORPORATION
WELDING PRODUCTS DIVISION
Dept. WJ-553, Milwaukee 1, Wisconsin
International Division: P. O. Box 2023 Milwaukee 1, Wisconsin, U. S. A.

A.O.Smith
WELDING PRODUCTS
Made by Welders . . . for Welders

Welding Arcs

PROPER CURRENT SETTING is easy with G-E single-dial dual control. Button for magnetic starter is at far end of set.



REDUCED NOISE, INCREASED PROTECTION provided by new WD-40 sets are important factors in multiple-welder areas.

New Magnetic Starter, Quieter Fan Improve G-E Welder Performance

You receive important new benefits from today's General Electric Type WD-40 arc welders. First, you get improved welder and electrical-system protection and lower maintenance with the new magnetic starter. Second, you get reduced operator fatigue, resulting in higher production, because of the new, quieter ventilating fan.

These improvements, plus present G-E features, combine to give you this unexcelled performance:

- **STEADY ARC,** providing high penetration and minimum popouts due to a unique generator interactor which smooths out current fluctuations.
- **QUICK RESPONSE, GOOD CONTROL,** for vertical and overhead welding without special adjustments.
- **ACCURATE CURRENT SETTING** for every job due to the wide current range and jumbo-size selector dial.
- **LOW OPERATING COSTS,** the result of high-efficiency design and high power-factor operation.
- **MAINTENANCE SAVINGS,** because of long-life construction and provision for easy inspection.

G-E WD-40 welders are built in ratings of 200, 300, and 400 amps, for every direct-current industrial application. Your nearby G-E welding distributor can supply you with complete information. He's listed here and in the yellow pages of your phone book under "Welding Equipment—General Electric." Get in touch with him today. General Electric Company, Schenectady 5, N. Y. 710-3

You can put your confidence in—

GENERAL ELECTRIC

News

Information on equipment, electrodes and accessories from G.E., pioneer in arc welding

Neutralize moisture pick-up with a DryRod oven

If you are using low-hydrogen or stainless-steel electrodes, don't sacrifice their quality by using electrodes exposed to humidity. Moisture picked up after the package is opened can cost you much of the built-in protection against under-bead cracking and porosity. The answer to this problem is a DryRod oven.

Installed at the job, this oven restores electrode efficiency and provides a convenient, dry storage place. For you this means fewer rejects and reworks, less X-ray porosity.

The DryRod Type 300 oven holds 350 pounds of 18 in. electrodes, has a temperature range of 175 to 550 degrees, yet weighs only 115 lb. See your nearby General Electric welding distributor for more details.

Copyright 1953, G.E. Company

Joe Magee says . . . Try W-29 rod for high-impact jobs

When welding on farm implements, road-building tools, and other equipment subjected to high impact, use G-E Type W-29 electrodes.

These Class E-6012 electrodes combine the smooth welding and minimum spatter of G-E Type W-28 electrodes with higher elongation and impact values than generally found in E-6012 deposits. It's also easier to produce more-complex fillets with W-29, for greater resistance to weld-bead cracking. And W-29's high burn-off rate means faster production.

Exceptional impact strength of W-29 deposits makes these electrodes particularly applicable for work subjected to low temperatures.

So remember, next time you have a high-impact or low-temperature application, use the electrode especially designed for the job: G-E Type W-29.

Free Electrode Book

Here's a handy reference book that you will find use for again and again on the job. It's General Electric's pocket electrode catalog which contains concise descriptive and application information on all G-E electrodes.

This useful booklet is available *only* through your General Electric welding distributor. Ask him for your free copy of GED-1634 today.

Here's the name of your G-E Welding Distributor—

Alabama: Birmingham—Alabama Oxygen, Young & Vann Supply; Mobile—Turner Supply

Arizona: Phoenix—Consolidated Welding Supply

California: Fresno, Los Angeles, Oakland, Sacramento, San Diego, San Francisco, Ventura—Victor Equipment

Colorado: Boulder, Colorado Springs, Denver, Durango; Ft. Collins, Ft. Morgan, Greeley, LaJunta, Longmont, Pueblo—Hendrie & Bolthoff

Florida: Hollywood, Miami—Florida Gas & Chemical

Georgia: Atlanta, Macon—Welding Supply & Service; Augusta—Marks Oxygen; Columbus—Williams Welding Supplies

Idaho: Boise—Olson Manufacturing

Illinois: Chicago, Moline, Morton—Machinery & Welder

Indiana: Evansville—Drill Master Supply; Ft. Wayne, Indianapolis—Sutton-Garten; South Bend—Perry Welding Sales & Service

Iowa: Des Moines—Machinery & Welder

Kansas: Coffeyville—Thompson Bros. Supply & Welding Equip.; Hutchinson—Kopper Supply

Kentucky: Louisville—Reliable Welding, Paducah—Henry A. Petter Supply

Louisiana: Alexandria, Shreveport—Hughes Oxygen; New Iberia—Welders Supply; New Orleans—Equitable Equipment; Opelousas—Daigle Welding Supply, Lake Charles—Welders Equip.

Maryland: Baltimore—Arcway Equipment

Massachusetts: Boston—New England G-E Welding Sales Division

Michigan: Detroit—Welding Sales & Engineering; Grand Rapids—Miller Welding Supply

Minnesota: Duluth—W.P.&R.S. Mars; St. Paul—Production Materials

Mississippi: Jackson—Jackson Welding & Supply

Missouri: Kansas City—Hohenschild Welders Supply; St. Louis—Machinery & Welder

Montana: Billings—Valley Welders Supply; Butte, Great Falls—Montana Hardware

Nebraska: Lincoln—Lincoln Welding & Supply; Omaha—Baum Iron

New Jersey: Kenilworth—Welding Sales

New Mexico: Albuquerque—Industrial Supply Co., Hobbs—Western Oxygen; Las Cruces, Silver City—Car Parts Depot, Inc.

New York: Buffalo—Welding Equipment Sales; Syracuse—Welding Engineering & Equip.

North Carolina: Charlotte—Dixie Gases, Gastonia—Gastonia Motor Parts

North Dakota: Bismarck, Fargo—Acme Welding Supply; Fargo—Dakota Electric Supply

Ohio: Akron, Cincinnati, Cleveland, Columbus, Dayton, Mansfield—Burdett Oxygen; Toledo—Odland Iron Works

Oklahoma: Tulsa—G-E Welding Sales Division

Oregon: Eugene, Portland—J. E. Haseltine

Pennsylvania: Philadelphia, Pittsburgh—Arcway Equipment

South Carolina: Columbia, Greenville—Welding Gas Products

South Dakota: Deadwood—Hendrie & Bolthoff

Tennessee: Chattancoga, Knoxville, Nashville—Welding Gas Products; Memphis—Delta Oxygen

Texas: Abilene—M&M Welding Supply; Alice, Corpus Christi—Crane Welding Supply; Alpine, El Paso, Marfa, Pecos—Car Parts Depot; Amarillo—Tex-Air Gas; Brownsville, Harlingen—Acetylene Oxygen; Dallas—Hill Equipment & Supply; Houston—G-E Welding Sales Division; Lubbock—Welders Supply of Lubbock; Midland—West Texas Welders Supply; Odessa, Pecos—Western Oxygen; Plainview—Plains Welding Supply; San Angelo—Southwestern Welding Supply; Snyder—Western Welding Supply; Texarkana—Hughes Oxygen; Wichita Falls—Nortex Welding Supply

Utah: Salt Lake City—The Galigher Co.

Washington: Seattle, Spokane—J. E. Haseltine

West Virginia: Bluefield—Bluefield Supply; Charleston—Virginian Electric, Huntington, Logan—Logan Hardware & Supply

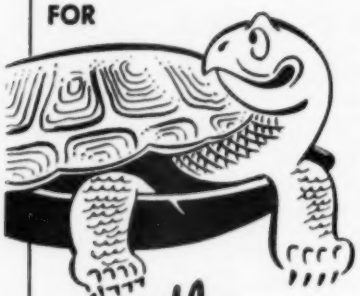
Wisconsin: Milwaukee—Machinery & Welder

Alaska: Anchorage—Northern Supply

Canada: Toronto—Canadian G.E.

Hawaii: Honolulu—American Factors, Ltd.

NATURE
PROVIDES
FOR



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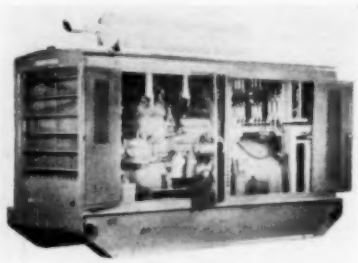
in claims for this holder is its economy as a screw-machine product. This is stated to result from savings in critical materials which materialize in lower initial replacement costs.

An additional facility of the Link electrode holder is the completely universal direction of water it offers. This permits on-the-job replacement or repair without pre-selection of point holders.

Further details on this item and other resistance-welding equipment can be obtained from Link Welder Corp., 13684 W. Buena Vista, Detroit 27, Mich.

Diesel Engine Generator

A new type, heavy-duty Diesel-engine generator, designed to improve the efficiency of large-scale arc welding operations for steel fabricating work in the field, has been developed by Ready-Power Co., of Detroit.



Engineered, sold and serviced by Ready-Power dealers everywhere, the 100-kw unit was built specifically for erectors of large-capacity storage tanks for liquid fuels and water. Other applications for the new generator include bridge building, and salvaging operations, and other steel work in the field requiring multiple welders. The generator was developed to overcome limitations of gas-driven welders in this type of application, from the standpoint of operating cost and efficiency.

The new Ready-Power unit provides for simultaneous operation of a bank of seven welders, and can also power a 50-hp electric air compressor plus a drop-cord line for operation of power tools and emergency lighting. Principal advantages it offers include (1) centralization of power source in a single unit for simplified control and maintenance; (2) ability to maintain welding efficiency at distances of several times greater than that of gas-driven welders, thus assuring a continuous bead and avoiding bubble formation when tack is broken; and (3) portability of the rectifier, which can be easily moved as required during progress of construction, thereby eliminating the need for elevation of the power source.

The new unit, designated as Ready-Power Model RD24A12, is powered by an International Harvester Diesel engine. It is fully equipped with protective controls and devices. Its structural steel base has high ground clearance and a wide skid for maximum mobility and flotation over rough or soft terrain. A weatherproof housing provides complete protection for outdoor operation.

A-C Welding Transformer

A new 400-amp single-phase a-c welding transformer with a 60% duty cycle has been announced by the General Electric Co.'s Welding Department.

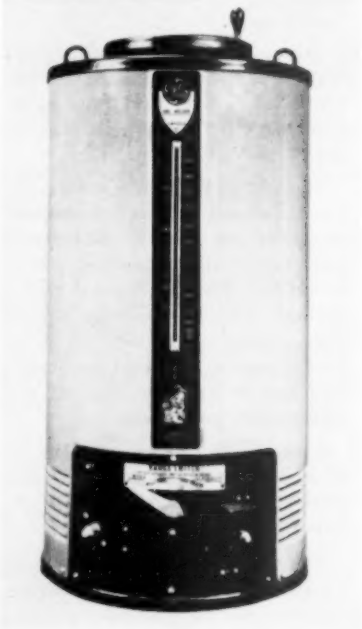
Designated as G-E Type WK40K, the new welder provides a current range of 40 to 500 amp, and can be used with a variety of electrode sizes for repair, maintenance and construction work.

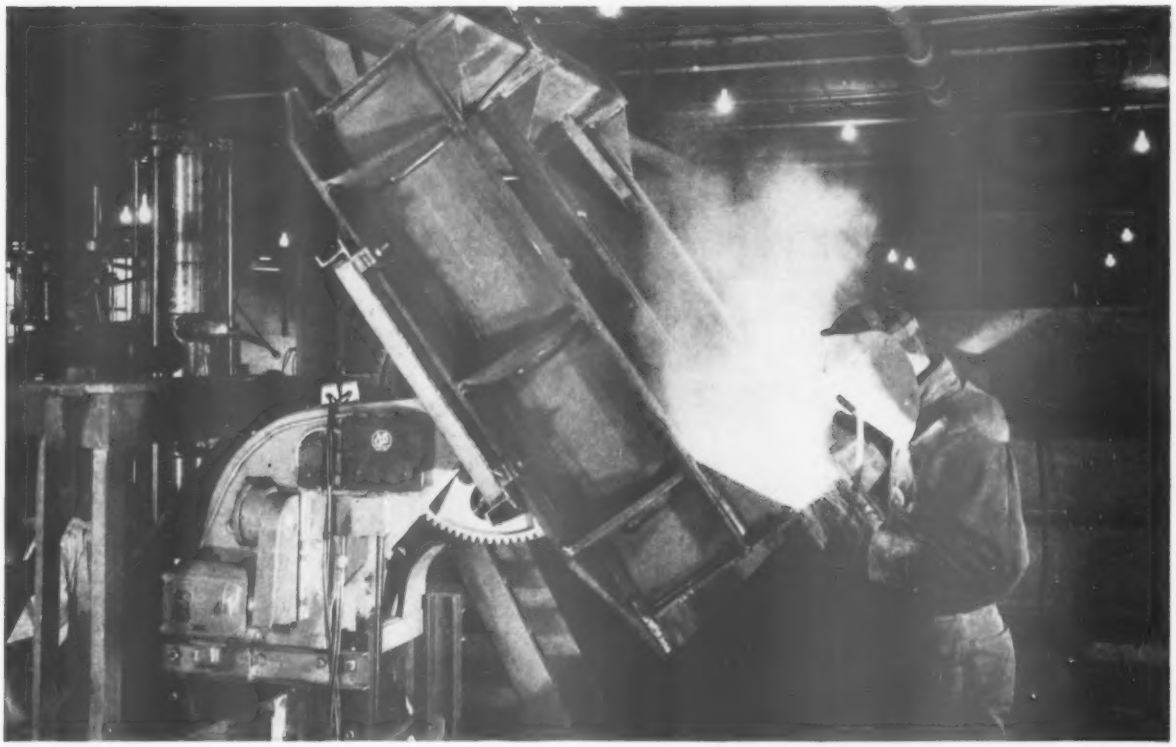
According to G-E engineers, the new transformer not only assures quick starting, but also incorporates arc-stabilizing capacitors which make it easier for operators to strike and maintain an arc without popouts. This results in faster travel speeds, fewer "patchups" and stronger welds, they said.

The extra-wide current range allows the use of this one machine for a wide variety of applications, from light-duty, low-current sheet metal jobs to heavier-duty, high-current industrial work. A range switch enables the operator to change quickly from high to low currents or vice versa.

Other advantages of the new welder are longer coil life, because of silicone insulation, stepless current control permitting accurate adjustment, and built-in idlematic control for protection against electric shock.

The new welder is 44 in. high, 22⅝ in. in diameter and weighs 355 lb.





WORTHINGTON WELDING POSITIONER ELIMINATES time-wasting handling of the work-piece . . . increases arc-time by tilting the work into position for continuous, economical downhand welding. Capacities from 100 lbs to 30 tons. Also: Turning Rolls from 3 to 150 tons, stationary and self-propelled.

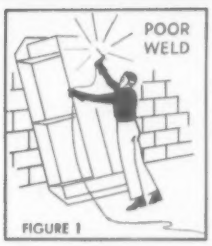
A way to get more and better welding from your welders

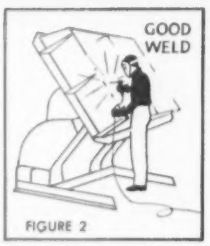
Every minute your welders spend climbing, turning and propping is *lost* welding time.

Turn this waste time into *all arc-time* with Worthington Welding Positioners that tilt or turn all welds into position—*without delay*—for *continuous* downhand automatic or manual welding. Today's labor scarcity makes this increased production more important than ever.

These Positioners lower costs and boost production up to 50%. Downhand welding is *quicker* (only one pass instead of two or three) . . . *better* (deeper penetration with higher current, heavier electrodes, faster deposition of weld metal) . . . *neater* (weld metal levels itself). There's less rod waste, too.

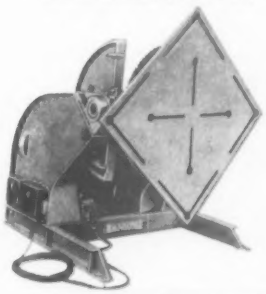
Where can you see a Worthington Welding Positioner at work near you? Just write Worthington Corporation, Plainfield, N. J., for this information or for Bulletin 210D.





HOW WORTHINGTON WELDING POSITIONERS PRODUCE BETTER WELDS

When the welder has to climb over, prop or flop the work-piece, he may only be able to use downhand welding over a limited area (Figure 1). With a Worthington Welding Positioner, the work is continually tilted or rotated automatically into position for downhand welding (Figure 2).



WORTHINGTON'S UNIVERSAL TABLE TOP makes the Welding Positioner as profitable on job work as mass production. Those "T" slots make the table adaptable to any shape of work-piece and a wide range of sizes. No special jigs or fixtures needed.

Y.2.3

WORTHINGTON

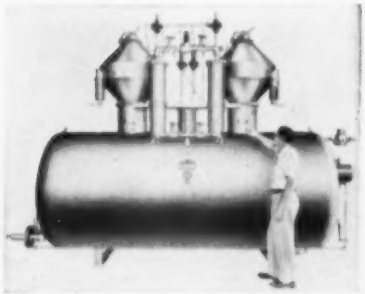
Welding Positioners
Turning Rolls

MODERNIZE Your PLANT

WITH A SIGHT-FEED

MODEL A-TWIN

ACETYLENE GENERATOR



Acetylene may be produced continuously, without necessity for shutting down operations at recharging periods.

• Safety is built into the Model A-Twin. Listed by U. L. and approved by F. M. Easy to operate.

• Saves you up to 50% or more of the cost of cylinder acetylene, 10% to 30% over conventional type single hopper type generators.

• Available in five convenient sizes to meet requirements for acetylene in your plant.

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WELDING Sight Feed EQUIPMENT

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Manufacturers of Welding Equipment for more than 25 years

Portable Arc Welder

The Royal-Arc hand-portable electric arc welder is a 110/220 hand-portable welder that has a heat range of 15 to 200 amp and more. It is lightweight and easily hand-carried from job to job. The Royal-Arc's "electronic brain" knows when to pour on that extra heat needed for industrial welding. Electrodes used are from 3/64 in. to and including 5/32 in. It has a 50% duty cycle.

Over-all length 10 1/2 in., over-all width 7 in., depth 6 1/4 in. Shipping weight approximately 65 lb.

One may weld, braze, solder, cut or preheat, using either the metallic-arc or carbon-arc process with the Royal-Arc.

Rod Solves Driver Burn Problem

Track crews usually build-up driver burns at the same time rail ends are repaired and use the same welding rod for both purposes. In many cases, however, the built-up burn will "cold roll" into a hardness greater than the surrounding area producing an undesirable secondary batter from train wheels. As the cost of new rail has been mounting rapidly, this problem has become serious for economy-minded railroads.

To meet this problem the Oxweld Railroad Service Co., a Division of Union Carbide and Carbon Corp., has developed a welding rod specifically for use in building-up driver burns. This new rod, the Oxweld Driburn rod, deposits weld metal equal in hardness to rail steel. The weld metal, therefore, wears at the same rate as the base rail steel and sharply reduces the possibility of secondary batter.

The Oxweld Driburn welding rod has the same excellent flow characteristics as the well-known Oxweld MW rod which is used to rebuild rail ends. Trackmen have found that the Driburn and MW rods are perfect mates on jobs where both driver burns and rail ends are to be serviced.

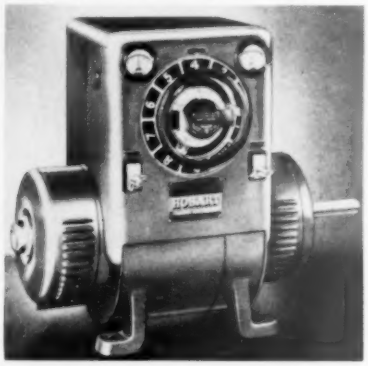
The Driburn rod is tipped with green for easy identification. It is available in 3/16- or 1/4-in. diameters. All rods are 36 in. long.

D-C Welding Generators

A complete new line of d-c welding generators (less motor) are now in production at Hobart Brothers Co., Troy, Ohio.

The "Build Your Own" welding generator (less motor) is made exclusively for direct coupling to the customer's gasoline engine, electric motor or belt drive from a motor or line shaft to form a low cost d-c arc welder.

The 200-amp "Bantam Champ" d-c welding generator is recommended for general welding. It has a welding range from 40 to 250 amp, and will handle as large as 3/16-in. electrodes for continuous welding. This model requires a gas engine with a rating of 20 bhp at speed of 2200 rpm, or an electric motor with a rating of 10 hp at speed of 2200 rpm.



The 300-amp model has a welding range from 40 to 400 amperes and includes an auxiliary power outlet plug of 1 kw capacity for use in operating small electric tools and lights. This 300-amp size is most popular with the average job welder who wishes to build up his own portable, gasoline-engine driven, arc-welding outfit at a saving. The reserve capacity of the 300 amp is best adapted for speedier handling of the heavier work. It requires a gas engine with a rating of 50 bhp at speed of 1800 rpm, or an electric motor with a rating of 20 hp at speed of 1800 rpm.

For complete information and specifications write Hobart Brothers Co., Department WG, Troy, Ohio.

Weld Flux Scaling Hammers

Three new Thor air-operated weld flux scaling hammers, featuring a small, lightweight, streamlined design, have been announced by the manufacturer, Thor Power Tool Co., Aurora, Ill.

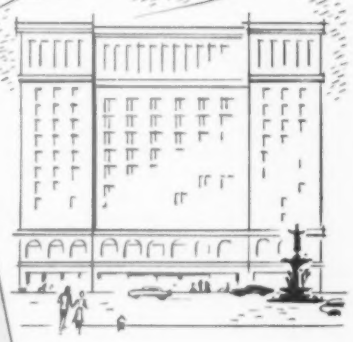
Only 7 3/4 in. long and weighing 2 1/8 lb, the new air hammers deliver the required speed and power for removing flux and splatter after welding. They are especially handy for corner welds and one-hand operation where space is a factor. Exhaust air, blown from four holes in the front of the barrel toward the work, removes loose chips and scale to maintain surface visibility.

LET'S TALK ABOUT MONEY SAVING ZIRTUNG

AT THE

National Welding Supply Association Show

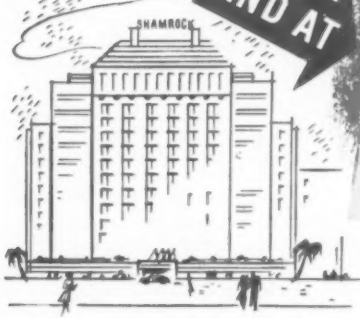
Sheraton-Gibson Hotel
Cincinnati, Ohio
May 11-12-13



AND AT

The Welding and Allied Industries Exposition

Shamrock Hotel, Houston, Texas
June 16-17-18-19
Booth No. 28



ZIRTUNG licks contamination problems

Zirtung, an exclusive Sylvania development, is the first electrode produced specifically for inert gas arc welding. It self cleans contamination without loss of electrode. Lasts longer . . . saves money in long runs. Wonderful for stainless and mild steels, aluminum, and magnesium.

For further information call your Sylvania Welding Distributor or write to: Sylvania Electric Products Inc., Dept. 3T-4905, 1740 Broadway, New York 19, N. Y.

SYLVANIA

LIGHTING · RADIO · ELECTRONICS · TELEVISION

In Canada: Sylvania Electric (Canada) Ltd., University Tower Building, St. Catherine St., Montreal, P. Q.

abstracts of CURRENT WELDING PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25c from the Commissioner of Patents, Washington, D.C.

2,629,922—Method of Brazing Resistor Terminals—Thomas E. Finch, Pittsfield, Mass., assignor to General Electric Co., a corporation of New York.

This patent relates to a copper brazing method for securing together a resistor unit of the sheath-insulated type to a terminal member and a resistance wire. The terminal member and resistance wire are placed in juxtaposition to form a joint with a body of brazing metal adjacent the joint and the terminal member and wire are positioned within a metal sheath spaced from the walls thereof. A mass of electrically insulating granulated refractory material is compressed into the sheath to embed the wire and joint. Lastly, the assembled unit is heated in a space containing an atmosphere including hydrogen and a gaseous oxidizing agent.

2,630,513—Argon Gas Feed Apparatus for Electrodes—William T. Redmond, Kennewick, Wash.

Redmond's patent relates to a welding torch having a metallic electrode with an insulating tube surrounding the electrode and defining an annular passage therebetween. A gas delivery line is connected to the passage and it includes gas storing means therein. These gas storing means include a sack which is encased in a container having a rigid frame.

2,630,514—Seam Welding Procedure—Walter S. Schaefer, East Gadsden, Ala., assignor to Republic Steel Corp., Cleveland, Ohio, a corporation of New Jersey.

This patent relates to a method of welding a seam along the cleft formed by the edge of a metal member abutting another metal surface. The method comprises arc welding the seam along one side of the cleft while controlling the arc welding to inhibit penetration of molten metal beyond a part of such depth, and pressing the metal edge against the other metal surface with sufficient force to forge weld a remaining part of the depth of the abutting area. Heat is maintained in the remaining part to effectuate the forge weld, which heat is at least in major part conducted from the arc-welding operation.

2,631,028—Torch Cutting Machine—Thomas F. Murr, Chicago, Ill., assignor to National Cylinder Gas Co., Chicago, Ill., a corporation of Delaware.

This novel torch-cutting machine is adapted to make a plurality of cuts along a plurality of different paths simultaneously. A horizontally movable carriage is provided and it has a plurality of cutting-torch carrying units supported on the carriage for movement transversely to that of the carriage. A motor-operated tracer unit is supported on the carriage for moving it and is connectable to at least one of the torch-carrying units to control the movement thereof transversely to movement of the carriage and to cause it to follow a predetermined path. At least one nondrive pattern-following device is supported on the carriage and is connectable to at least one of the torch-carrying units to control the transverse movement thereof to cause the unit to follow a path corresponding to that followed by the pattern-following device but with such path being different from that followed by the torch-carrying units controlled by the tracer unit.

2,631,214—Composite Metal Manufacturing Apparatus—Robert E. Kinkead, Shaker Heights, Ohio, assignor to the Cleveland Trust Co., Cleveland, Ohio, a corporation of Ohio, as trustee.

This patented apparatus for cladding a slab of metal includes a support, a plurality of contactor carriers and a plurality of electrode contactors supported by each carrier. Means suspend the carriers along and above the slab support and such means can move the carrier and associated contactors to an open circuit position. A source of welding current is electrically connected to the contactors and to a slab mounted on the slab support.

2,631,215—Welding System—John F. Randall, Detroit, and Richard E. Brooks, Dearborn, Mich., assignors to Ford Motor Co., Dearborn, Mich., a corporation of Delaware.

Apparatus for electrically welding sheet metal parts in edge-to-edge relationship is disclosed and covered in this patent. The apparatus includes a pair of opposed clamping members one of which is provided with a groove for the reception of the welding electrode. The other of the clamping members comprises a block of elastomer upon which is supported at least two laminations of highly heat conductive metal. Two edges of the laminations are joined together to form a cooling conduit.

2,631,257—Automatic Alternating Current Arc Welding System—Alfred F. Chouinard, Chicago, Ill., assignor to National Cylinder Gas Co., Chicago, Ill., a corporation of Delaware.

An automatic arc welding system is disclosed wherein a welding electrode is fed toward work and an arc is maintained between the electrode and the work. An electric motor is provided for feeding the electrode and a transformer having a primary winding with a relatively small number of turns is connected for energization across the arc. The secondary winding of a transformer has a relatively large number of turns and is connected to energize the motor at a voltage substantially higher than the arc voltage. The energy for operating the motor is derived solely from across the arc.

2,631,361—Method of Making Welded Tubing from Strip Metal Stock—Arthur M. Wallace, Detroit, Mich., assignor to Bundy Tubing Co., Detroit, Mich., a corporation of Michigan.

This new tube-making method uses strip metal stock, and the method comprises fashioning portions of the strips which lie between a longitudinal intermediate section and opposite edge portions of the strip into curvilinear form, which curved sections extend in opposite directions relative to the intermediate section. The intermediate section and the opposite edge portions are maintained substantially straight and the opposite edge portions are brought into positions substantially perpendicular to the intermediate section and on opposite sides thereof and in offset relation to each other. The interfaces are welded together and the intermediate section is cut at the location between the outside surfaces of the edge portions to provide two separate tubes each of which has an angular formation in its wall. Lastly, the tubes are rounded into substantially circular form in cross section.

2,632,079—Means and Method for

ELECTRIC SEAM WELDING—Alfred C. Body, Cleveland, Ohio, assignor to the Ohio Crankshaft Co., Cleveland, Ohio, a Corporation of Ohio.

Body's patent relates to the art of heating the edges of a C-shaped tube and welding the tube to form a pipe. The patent includes roller means for bringing the edges of a tube into pressure engagement and relatively narrow high-frequency inductor means, adapted to induce currents to flow parallel to the edges and to heat the edges only, are provided. Additional inductor means are positioned between the high-frequency inductor means and the roller means for inducing currents to flow circumferentially in the tube and between the edges as they are brought into contact.

2,632,080—WELDING ELECTRODE—Rene D. Wasserman, Stamford, Conn.

The patented electrode is for welding aluminum and it has a core which comprises 85 to 93% aluminum and 7 to 15% silicon. A coating is provided on the electrode and comprises 15 to 45% of a metal fluoride and with the remainder of the coating being a metal chloride.

2,632,081—ARC-WELDING APPARATUS—Robert L. Evans, Indianapolis, Ind., assignor to Western Electric Co., Inc., New York, N. Y., a corporation of New York.

An arc-welding apparatus for welding two annular metal parts at their abutting annular edges is covered in this patent. A combined base and electrode is adapted to support one part and is connected to a welding circuit. Means clamp the other of the parts in engagement with the first-mentioned part, and drive means rotate the combined base and electrode to move the line of juncture of the two parts in a predetermined path. A welding electrode is positioned for reciprocation adjacent the line of juncture of the parts on the base, such means moves the electrode across the line of juncture of the parts to associate the electrode alternately with the edge portions of each of the parts.

2,632,835—COATED WELDING ELECTRODE—Rene David Wasserman, Stamford, Conn.

This patent is upon a coated welding rod having a core of stainless steel which includes between 17 to 20% chromium, 8 to 10% nickel, 1 to 3% manganese and the balance substantially all iron. The coating on the core has relatively large quantities of chromium metal powder and titanium dioxide therein together with small amounts of other materials.

LIST OF NEW MEMBERS

Effective March 1, 1953

ARIZONA

Maffeo, John H. (B)
Sferra, Robert W. (B)

BIRMINGHAM

Farlow, James C. (B)
Jones, Bruce, M., Jr. (C)
Jones, Russell E., Jr. (C)
Kelley, Raymond J. (B)
Miner, J. W. (B)

BOSTON

Connolly, Edmund J. (C)
Duffney, David N. (B)
Ernst, Karl L. (B)
Hellmer, Carl M. (B)
Rosenberg, Allan J. (B)

CHATTANOOGA

Barrett, Raymond E. (C)
Brooks, Howard V. (B)
Denton, Floyd J. (B)
Guider, Robert M. (C)
Kilgore, Raymond L. (B)

CHICAGO

Andrews, Floyd J. (C)
Witbeck, A. L. (C)

CINCINNATI

Weisenberger, Fred (C)

CLEVELAND

Laurence, Howard F. (C)
Noss, Herbert M. (B)
Scarpitti, Albert W. (B)
Sweda, Ted I. (C)
Traum, Carl (B)

COLORADO

Besser, Arthur A. (B)
McKinnis, J. B. (C)

COLUMBUS

George, Edwin R. (B)
King, James Richard (B)
Slob, Walter (C)

DALLAS

Douglas, Alson H. (C)

DAYTON

Hall, Joseph W. (C)
Utermoehlen, Louis C. (B)

DETROIT

Allen, Robert T., Jr. (B)
Barrett, Joseph G. (C)
Bielecki, Anthony A. (B)
Budzinski, William (C)
Cheney, Orvell V. (B)
Church, John G. (B)
Clarke, William A. (B)
Cobb, William H. (C)
Custance, Don (C)
Elliott, Lauren F. (B)
Evaul, Robert (C)
Fulton, Robert M. (B)
Fulton, William A. (B)
Gaydos, Ernest N. (C)
Gordon, Paul (B)
Graham, T. C. (C)
Gudebski, H. (B)
Heiden, Ray (C)
Heslop, Arthur (C)
Hopper, Otis (C)
Jeanne, Ernest G. (B)
Jeanne, Gaston (B)
Krantz, William W. (B)
Lanzen, Joseph W. (C)
Leith, Charles R. (B)
Lohrber, Albert E. (B)
Nagler, Charles Arthur (B)
Orgeck, Arthur A. (B)
Ostrowski, Harry J. (C)
Rivers, Gordon E. (B)
Salinger, S. T. (C)
Sanson, Anthony (C)
Smith, Lawrence E. (C)
Trygar, Michael H. (C)
Wight, Robert (C)
Wilbur, W. T. (C)
Wood, David D. (B)

EAST TEXAS

Barlow, Delton D. (D)
Grusing, David (D)
Hickman, Robert (D)
Kamradt, Robert George (D)
Tyler, H. T. (C)
Whittle, Chesley G. (D)

HOUSTON

Bernson, Albert, Jr. (B)
Goodere, William Earle (B)
Higham, Gordon B. (C)
Morgan, Preston D. (B)
Sullivan, D. B. (B)
Thompson, Melvin J. (C)

INDIANA

Dobbins, Donald A. (B)

IOWA

Pettijohn, Ray R. (B)

KANSAS CITY

Thomas, Omer F. (B)

LEHIGH VALLEY

Hartzell, William F. (B)
Schoeneck, Joseph W. (C)

LONG BEACH

Cox, Ted (B)
Nelson, James B. (B)
Pfrunder, Charles J. (B)
Wortham, Robert B. (B)

LOS ANGELES

Gaver, Raymond H. (B)
Hurzeler, J. E. (C)
Lessing, Paul L. (C)
Logan, William Francis (B)
Peck, Robert S. (C)
Simon, Walter S. (C)

MARYLAND

Blenckstone, Fred E. (B)
Donohue, John C. (C)
Edwards, Roger H. (C)
Forsythe, George E. (C)
Line, John Chester (C)
Wingert, Donald E. (C)

MICHIANA

Gaskill, Fred A. (C)
Riley, Robert (C)

NEW JERSEY

Collins, Francis E. (C)
Mann, Harry D. (C)
Skinner, Alexander (B)

NEW YORK

Cartier, Marius (B)

Fedorocko, John (C)
Gunsten, H. Kenneth (C)
Heim, Russell H. (B)
Maddalena, A. Edward (B)
Rattelle, Lawrence W. (B)
Schwartz, Sidney D. (B)
Smith, David (B)

NIAGARA FRONTIER

Bole, Albert C. (B)

NORTHEAST TENNESSEE

Adams, J. O. (B)
Armstrong, C. Dale (B)
Barnett, James H. (C)
Berryhill, M. E. (B)
Bledsoe, Leonard R. (B)
Boykin, J. P. (B)
Broom, J. R. (C)
Byasses, I. P. (B)
Case, Jack Marion (B)
Chadwick, R. M. (C)
Chance, J. E. (B)
Cleveland, Herbert (B)
Cochran, C. R. (B)
Collins, W. C. (B)
Cooper, Hugh H. (B)
Culberson, V. H. (B)
Dempster, Richard R. (B)
Douglas, T. E. (B)
Elrod, E. F. (B)
Estes, Chester L. (B)
Fox, Richard J. (B)
Fultz, James D. (B)
Graves, Russell L., Jr. (B)
Green, G. M. (B)
Harlan, Hubert B. (B)
Hawk, Charles William (B)
Hawkins, C. C. (C)
Heider, E. Milton (C)
Hemphill, Leo F. (C)
Henley, L. W. (B)
Hickey, Charles C. (B)
Hodge, L. A. (B)
Houchin, V. T. (B)
Housley, T. R. (B)
Hubbs, H. D. (B)
Jeffers, Homer (B)
Johnson, Charles S., Jr. (B)
Johnson, Graham E. (B)
Johnson, J. H. (B)
Kittrell, E. Maurice (B)
Leonard, W. J. (B)
Leopold, F. S. (B)
Linville, E. R. (B)
Linville, Roy E. (B)
Ludwig, Floyd H. (B)
Luttrell, Edward (B)
Mahegan, D. J. (B)
Marks, J. Loy (B)
Marlin, Frank (B)
McGraw, B. L. (B)
McGuffey, J. R. (B)
Mims, Grover Ray, Jr. (B)
Morford, Roy C. (C)
Moore, Kenneth N. (B)
Morris, Lonnie A. (B)
Oldham, H. J. (C)
Olsen, Arnold R. (B)
Patriarca, Peter (B)
Patrick, J. H. (B)
Price, J. C. (B)
Roberts, T. G. (B)
Russell, T. J. (B)
Schabot, Robert E. (C)
See, George C. (B)
Shattuck, Frank, Jr. (B)
Shoptaw, Howard M. (B)
Siegener, John J. (B)
Siler, S. C. (B)
Simpson, Albert L. (B)
Smith, Gene R. (B)
Smith, Walter W. (B)
Snuggs, W. Howard (B)
Swindell, Thomas C. (C)
Temple, J. T. (B)
Thompson, James C., Jr. (B)
Thorpe, James R. (B)
Troutman, S. W. (B)
Williams, C. A. (B)
Wyrick, H. F. (C)
Wyrick, H. M. (B)

NORTHERN NEW YORK

Fleischmann, Walter L. (C)
Fleming, Laurence J. (B)

NORTHWEST

Alman, Kenneth (C)

NORTHWESTERN PENNSYLVANIA

Loomis, Philip M. (C)
Peterson, Harry J. (C)
Walker, B. J. (C)

OKLAHOMA CITY

Briscoe, Harry W. (C)
Calvert, Foster (C)
Flurry, Hazen R. (D)

PASCAGOULA

Baker, Neal A. (C)
Ball, Richard E. (C)

PHILADELPHIA

Ashworth, William Edward (B)
Collins, Mark L. (B)
Gearhart, Samuel W., Jr. (B)
Jaggers, Harry (C)
Murphy, Joseph J. (C)

PITTSBURGH

Halsley, Frank A. (B)
Griffiths, Carl B. (B)
Hudson, Charles H., Jr. (C)
Hurst, Thomas W. (C)
McCarrell, William W. (B)
Oeler, James J. (C)

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Meadow, Casimer A. (C)
Taylor, Hugh F. (C)

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Shaffer, W. H. (B)
Simpson, Raymond M. (B)

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Watkins, John E. (B)

SYRACUSE

Davis, Lyle E. (C)

TOLEDO

Schmidt, Walter F. (C)
Wolcott, John L. (B)

TRI-CITIES

Green, Tom (C)

TRI-STATE

Busch, John M. (B)

TUCSON

Adkins, M. H. (B)
Armstrong, Henry E. (C)
Arner, Gilbert E. (B)
Autrey, William L. (C)
Bain, Floyd E. (B)
Ballenger, Paul S. (B)
Balz, Clarence L. (B)
Blake, R. A. (B)
Buza, Andy (B)
Camacho, Ramon M. (B)
Campbell, James S. (C)
Chapman, Donald M. (B)
Clendenning, H. I. (B)
Codner, Earl F. (C)
Condron, Charles M. (B)
Currie, William C. (C)
DeLeon, Jesus (C)
Douglas, Brainard E. (B)
Fecke, Floyd (B)
Fisher, Leo V. (B)
Fisher, Richard L. (C)
Fraizer, S. J. (B)
Golay, Oliver M. (B)
Graham, Richard S. (C)
Graves, Auty E. (B)
Hagan, Ed (B)
Hansen, Allen F. (C)
Kay, Otis B. (B)
Kubishke, Emil (C)
Kushmaul, George (C)
Mahoney, W. James (B)
McClung, John W. (C)
McCowan, Donald E. (B)
Moore, G. L., Jr. (B)
Murphy, Ross B. (B)
Normart, Frank J. (B)
Nuttycombe, Ray (B)
Quinland, Joe V. (B)
Scott, Lawrence D. (C)
Smith, Elbridge D. (B)
Smith, Robert S. (C)
Spillman, Bill (B)
Stahl, Clifford A. (B)
Tillotson, Dean (C)
Tracy, Mack B. (C)
VanWormer, B. Ray (B)
Voorhees, Franklin E. (B)
White, Dewey (B)
Wilkerson, C. J. (B)
Wilson, R. C. (B)
Zimmerman, Walter C. L. (B)

TULSA

Black, Jess R. (B)
Gay, Charlie W. (B)
Weeks, Lloyd W. (B)

WASHINGTON, D. C.

Davis, Kenneth (C)

WESTERN MASSACHUSETTS

Weinack, John (B)

YORK-CENTRAL PENNSYLVANIA

Nivison, Robert B. (C)
Warnick, Arthur C., Jr. (C)
Zinkand, William C. (C)

NOT IN SECTIONS

Ardagh, Ki (C)
Cook, R. L. E. (B)
Lefebvre, Jacques J. (C)
Lennie, John (B)
Wiley, Richard C. (B)

Members Reclassified

During the month of March

CHICAGO

Carlson, Irving H. (C to A)

LOS ANGELES

Stevenson, Francis H. (C to B)

(*Continued from page 423*)

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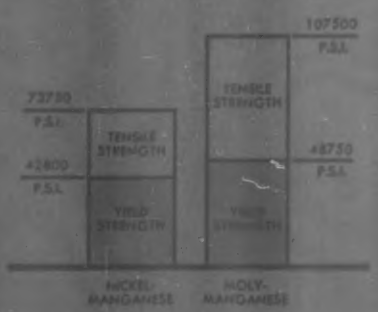

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SECTION NEWS AND EVENTS

as relayed to C. M. O'Leary

Rigid Frame Design

Bethlehem, Pa.—One hundred and twenty members and guests of the *Lehigh Valley* Section were present on March 2nd to hear Martin P. Korn AWS, of Giffels & Valet, Inc., give a semitechnical talk on "Adventures in Rigid Frame Design."

Sixty-four members and guests were present at the dinner preceding the meeting, both of which were held in the Hotel Bethlehem. Coffee speaker was W. S. Cummings, Jr., of the Bethlehem Steel Co., who spoke on his trip to an iron ore field in Labrador.

Laboratory Inspection

Boston, Mass.—The *Boston* Section was fortunate in receiving an invitation from the Metallurgical Department of MIT for the Section members and their guests to inspect the new Alfred P. Sloan Metal Processing Laboratory and conduct their March 9th meeting in one of the Lecture Rooms. This building, recently completed, is now occupied by the metal processing division of the Metallurgical Department. This new and up-to-date laboratory places MIT in the fore among the many engineering schools of the country that teach and investigate metal processing. Welding is properly emphasized, which is really a new development.

After dinner those present were divided into groups and conducted through the building by selected students to describe its important features. The technical session that followed was conducted by Prof. Harry Udin, Assistant Professor of Metallurgy, in charge of the Welding Laboratory. Professor Udin is also the Section's popular technical chairman. His talk was about "Failures in Welded Steel Structures." He has much first-hand information concerning failures that have been publicized during the last few years on bridges, storage tanks, boats, etc. His talk was very instructive, especially in the light of what is now known regarding brittle fractures at normal temperatures and sometimes low temperatures. While weld failures are infrequent they should be mostly termed "design failures."

Design for Welding

Bridgeport, Conn.—J. Mikulak AWS, of the Worthington Pump Corp., Harrison, N. J., was the guest speaker at the March 19th meeting of the *Brideport* Section held at Rapp's Restaurant, Shelton. Mr. Mikulak's subject was on "Product Design for Welding."

Welding Metallurgy

Buffalo, N. Y.—The February dinner meeting of the *Niagara Frontier* Section was held on February 26th at the Hotel Sheraton. Technical speaker was Anton L. Schaeffler AWS, Metallurgist, Welding Research, Allis-Chalmers Manufacturing Co., Milwaukee, Wis. Mr. Schaeffler's subject was on "Simplified Metallurgy for Welders and Welding Supervisors." He discussed the major factors that the welder must consider when he is welding mild steel, low-alloy steel, stainless steel and dissimilar steels. Colored diagrams were used to illustrate the metallurgical changes that occur during welding. Fundamental principles of welding dissimilar metals were outlined.

Mr. Schaeffler received his undergraduate training at Marquette University and a Master's Degree at the University of Wisconsin. He worked as a cooperative student at Harnischfeger Corp. Following graduation in 1942 he spent three years at A. O. Smith Corp. From 1945 to 1950 he had charge of the metallurgical section at Arcos Corp. He is now working on welding problems in the Research Laboratories of Allis-Chalmers.

Student Training

Cincinnati, Ohio.—"Training of Welding Students" was the subject presented by Robert Bercaw AWS, Head of the Hobart Trade School, at the regular monthly meeting of the *Cincinnati* Section held on March 24th at the Engineering Society Headquarters. Mr. Bercaw has been Head of the Hobart Trade School for many years and has had many years of practical welding experience. Therefore, he is in a position to cover both the technical and practical side of welding. His services are greatly in demand as, in addition to his training duties, he is sent all over the country for the Hobart Brothers Co. on special welding problems.

Stainless Steel

Cleveland, Ohio.—The March dinner meeting of the *Cleveland* Section was held on the 11th in the Mather Room of the Hotel Allerton. Coffee speaker was D. M. Hodgkinson of the Northern Ohio Institute (Dale Carnegie), who lectured on the art of public speaking.

Speaker at the technical meeting was George E. Linnert AWS of the Armco Steel Corp. Mr. Linnert gave an excellent extemporaneous talk on the "Fabrication of Stainless Steel."

Ninety members and guests attended the dinner and 100 were present at the meeting.

Fixtures

Dallas, Tex.—An excellent discussion on "Fixtures for Automatic Welding" was given by Ralph A. Trentham of the Reed Engineering Co. at the March 23rd meeting of the *Dallas* Section.

Rectifier Welder

Dayton, Ohio.—The February meeting of the *Dayton* Section was held on the 10th at the Engineers Club, Dayton, Ohio, with 40 people in attendance.

The guest speaker was Harry Bichsel, Westinghouse Corp., Pittsburgh, Pa. His subject "Development and Characteristics of the Rectifier Welder," covered the development and the characteristics of the rectifier welder; a comparison of the d-c welder with the rectifier; operating costs, its uses, etc.

A slow-motion color film of the welding arc was also shown, as was an Airco film on sigma welding.

Resistance Welding Controls

Dayton, Ohio.—The March meeting of the *Dayton* Section was held at the Engineers Club, on the 10th, with 56 in attendance.

The guest speaker was H. Colestock, Weltronic Corp., Detroit, Mich. His subject "You Asked for It—Electronic Contro! Design and Techniques of Resistance Welding," covered the development of the controls for spot welding. His talk implied that most of the development has been the result of people who use spot welders requiring or requesting these additional controls.

The talk was profusely illustrated by slides showing the development from the

simpler type of timers and controls to the present types of very complicated nature that are now being used in special applications.

The attendance was the largest single attendance at any meeting this year, indicating the interest in the subject. There was a lively question-and-answer period lasting at least an hour and on into the coffee and doughnut period that followed.

Welding Design

Denver, Colo.—The *Colorado* Section held its regular monthly meeting on March 10th in the Festival Room of the Oxford Hotel. Commander J. R. Plumb, Inspector of the Denver Naval Reserve, gave some first-hand information on the operation of the Naval Reserve Training Program.

Speaker at the technical meeting was Herman A. Geller [MW], of the Stearns Roger Mfg. Co., Denver. Mr. Geller covered new methods, applications and processes in his subject "Welding Design as Applied to Production and Engineering."

An after-meeting feature was the showing of a 16-mm sound color film on the subject "Phonevision." This excellent film was shown through the courtesy of the Ideal Pictures Co. of Denver.

Civil Defense

Detroit, Mich.—The *Detroit* Section held a nontechnical meeting on Civil Defense on Friday, February 13th, in the Rackham Building, Engineering Society, Detroit. Coffee speaker was Inspector Beryl J. Pace who is in charge of civil defense for the Detroit Police Department and responsible for recruiting, selecting and training of the emergency police reserve. His talk well illustrated the problem of civilian defense in Detroit as well as the need for cooperation from citizens and industries.

The other speaker of the evening was P. C. McGillivray, who is Civil Defense Operations Coordinator, office of Civil Defense, Detroit, serving under Brig. Gen. Clyde E. Dougherty, Director of Civil Defense. Mr. McGillivray spoke at length on "Civil Defense—Step Child of our National Defense" and, with movies and illuminated models of cities, emphasized the tremendous preparation needed for our Civil Defense program, now, in a cold war, and in case of an eventual shooting war.

Electrodes

Fort Wayne, Ind.—The February 20th meeting of the *Anthony Wayne* Section included a dinner at the Howard Johnson Restaurant; a film "No Finer Electrodes Made—Anywhere"; and an explanation of AWS classifications of mild steel electrodes.

The meeting started with dinner at 6:30 and was followed by the first "inside story" of how arc-welding electrodes are made. "No Finer Electrodes Made—Anywhere" is a full-color sound production on the entire manufacturing process of coated electrodes.

The meeting moved to Bob McCoy's Welding Works at 1216 W. Wayne St. in Ft. Wayne. Lloyd Noel, Welding Instructor for the Fruehauf Trailer Co., gave demonstrations of each type of rod on scrap plates and welded in the positions indicated for that type of rod. With the aid of a wall chart made for this demonstration, D. B. Rice described the rods as specified in AWS classifications. The presentation by Mr. Rice was extremely well-prepared and gave a clear description of welding rods and their uses.

Health Hazards

Grand Rapids, Mich.—The *Western Michigan* Section held a very enjoyable meeting on Monday, March 23rd, at the Michigan State College in East Lansing, Mich.

From 3:00 to 5:00 in the afternoon there were guided tours through the Mechanical Engineering Department of the College. From five until dinnertime the members and guests were free to tour the campus which is one of the most beautiful in the United States.

Dinner was at the Michigan State Union and was attended by 67 members and guests. The Coffee Speaker was Doug Weaver, a member of the 1952 Michigan State National Champion Football Team. Doug showed the colored film of the 1952 Michigan-Indiana game and narrated the plays. He was a very interesting after-dinner speaker and his play-by-play account of the game was most enlightening.

The Technical Session was addressed by Bernard Bloomfield, Engineering Consultant with the Division of Industrial Health of the Michigan Department of Health. The lecture was on health hazards associated with welding and methods of ventilating welding operations. Mr. Bloomfield showed a 12-minute film on ventilating methods and covered all the various health hazards connected with welding and its allied operations. Mr. Bloomfield, as a consultant for the Department of Health, will go to any shop and study the health hazards and give the company his recommendations for eliminating them. He related several of his experiences in some of the larger shops, which proved very interesting.

Rectifier Welders

Houston, Tex.—The March meeting of the *Houston* Section of the AWS was held at the Ben Milam Hotel on the evening of the 26th. The principal speaker for the evening was G. K. Willeke, a physicist with the Miller Electric Manufacturing Co. of Appleton, Wis. Mr. Willeke, a graduate of Central State Teachers College in Wisconsin, majoring in physics. Graduate work was done at the University of Wisconsin and Ohio State. After teaching high school physics for several years, he was appointed instructor in physics at Lawrence College in Appleton in 1942.

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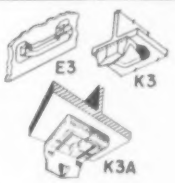

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In 1945 he went to Wright Field as head of the Advanced Radiation Unit, studying infrared and cosmic radiation for the Air Force. Later, he returned to Lawrence College to become Assistant Professor of Physics.

In 1945, Mr. Willeke became associated with the Miller firm as a consultant. In 1950 he resigned his position with Lawrence College to become physicist and technical editor with Miller.

Mr. Willeke's talk was a down-to-earth technical discussion of the basic principles of the rectifier-type welder, couched in language that was readily understood by welding engineers and operators not too familar with complex electrical theory. The requirements for a direct-current welding supply were established and then the various steps in the solution of the problems involved were analyzed. The detailed function of each component part was discussed and examined as to its place in the completed machine.

Special attention was given to the characteristics of the welding current as produced by the various welding power supplies and the effects of the various types of currents on welding.

Prior to this most enlightening talk, the SOCIETY enjoyed a keg, a movie and a delicious steak dinner. Eighty-two members and guests participated in this most enjoyable evening.

Conducted Tour

Long Beach, Calif.—A tour, arranged by Capt. C. M. Tooke [AWS], 2nd in Command of the Long Beach Naval Shipyard, was made through the drydock, machine shop, pipe shop, structural shop and industrial laboratory of the shipyard by members of the *Long Beach* Section on February 20th. The work going on in the various departments was explained in detail by the guides. The members also had an opportunity to see the largest crane on the Pacific Coast which was brought from Germany after the late war.

Dinner in the Shipyard Cafeteria preceded the tour. After the dinner a short talk was given by Ron Davis [AWS], Division Superintendent of the Yard, outlining the route to be taken in the plant visit. One hundred and seventy-five members took part in the tour.

Aircraft and Rocketry Panel

Los Angeles, Calif.—The February 5th Aircraft and Rocketry Welding Panel of the *Los Angeles* Section was held at Sally's Cafe with an attendance of 29 at dinner and 33 at the meeting. Subject of this panel was "Applicability of the AWS Fusion Welding Symbols." Speaker was H. L. Meredith [AWS], Secretary of the Panel. Moderator was Charles B. Smith [AWS], Publicity Chairman. Some of the high lights of Mr. Meredith's address were as follows:

Welding takes its proper place as an engineering tool when provided with the means for conveying precise information from the designer to the workman. The AWS System is an old system of weld notation which probably should have been used and established some time before this as a regular procedure. Indications are that the AWS System is gaining more widespread use in commercial enterprises. Mr. Meredith used seven large cards to review the basic form of the welding symbols. The first three cards presented information pertaining to the standard location of welding symbol elements. The fourth and fifth cards showed, in detail, seven basic types of welds and their respective joint preparation. The fourth card represented the five most standard types of welds: Bead, Fillet, Square Butt, Single, Bevel, and Double Bevel or "V" Groove. The fifth card illustrated the "U" and "J" groove types of welds, these he called "Special Joint Preparation."

Three additions were presented to the panel for comment, discussion and possible approval. They were: (1) Add the radius dimension of groove welds (joints) "U" and single "J" to the *Groove Depth* and *Root Penetration* dimension presently used. (2) Revise the rule governing the use of the *Convex Contour* symbol with a finish symbol. (3) Add a new ideograph that would represent a *Square Butt* joint which required a definite amount of "drop through" by a "welded from one side" operation.

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Battle of the Sections

New York, N. Y.—On March 10th the *New York* Section played host to visiting teams from the New Jersey, Philadelphia and Maryland Sections in a "Battle of the Sections." This was an old fashioned quiz program testing the welding knowledge of the different teams in a battle of wits.

J. Lyell Wilson of the New York Section acted as Moderator, and did an outstanding job in keeping the program moving at high pitch. After a lively and closely contested session, the Maryland Section emerged as the victorious team. As the winners, each member of the Maryland team was awarded a pen desk set. The audience also participated in the quiz with John H. Painter of the New York Section winning a prize for the best question from the audience to stump the experts. The team members were as follows:

Maryland Section: E. B. Lutes (Arcrods Corp.); F. Albrecht (Glenn L. Martin Co.); G. E. Linnert (American Rolling Mills Co.).

Philadelphia Section: R. Bradway (New York Shipbuilding Corp.); J. J. Mac-

Kinney (The Budd Co.); F. Judelsohn (J. A. Cunningham Equipment Co.).

New Jersey Section: R. Wilson (International Nickel Co.); W. Bunn (M. W. Kellogg Co.); G. Gibson (Air Reduction Research Laboratories).

New York Section: J. Mikulak (Worthington Corp.); H. Robinson (Kaiser Aluminum & Chemical Sales, Inc.); M. J. Letich (American Bureau of Shipping).

The contest was judged by three members of the visiting Sections, and their's was a difficult job which they handled admirably. The judges were S. Baum, U. S. Naval Shipyard, representing the Philadelphia Section; B. Ronay, U. S. Naval Academy, Engineering Experimental Laboratory, representing the Maryland Section; and T. Smith, Bethlehem Steel Co., Shipbuilding Division, representing the New Jersey Section.

The winning team was determined from their answers to previously selected questions addressed to each team in rotation by the Moderator. Four rounds of questions tested their knowledge of oxyacetylene welding, electrodes and arc welding, resistance welding, and inert-gas-shielded arc welding. After the winning team was selected, questions were directed to the experts by members of the audience with many practical questions being fired at the team members.

The meeting was well attended and from the response from the audience in trying to stump the experts themselves, it was evident that everyone had a good time. These meetings where the New York Section can welcome members from other Sections of the SOCIETY have always proved to be successful and enjoyable.

Rectifier Welders

Newark, N. J.—The regular monthly meeting of the *New Jersey* Section was held on March 17th.

"Rectifier Welders versus Welders of the Rotating Type" was the main topic of the evening presented by A. U. Welch [AWS,] Manager of Engineering for the Welding Department of General Electric Co. Approximately 85 members and guests profited from the fundamental and clear comparison of the merits and disadvantages of the two types of welding machines that are widely used at present. The timeliness of the subject was evidenced by the long lively discussion period that followed Mr. Welch's talk.

Prior to the formal meeting, arrangements were completed for the Annual Picnic held each September.

Welding Metallurgy

Oklahoma City, Okla.—The sixth meeting of the season was held by the *Oklahoma City* Section on February 26th in Jack Barnes Clubroom. P. L. Willson, Chief Metallurgist of the Halliburton Oil Well Cementing Co., Duncan, Okla., presented an excellent talk entitled "The Metallurgy of Welding." Mr. Willson presented the subject in a way that welding operators and technical people alike thoroughly understood the importance of the welding operator and what he does. In addition to his talk, Mr. Willson presented two sound films entitled "The Science of Oil Well Testing" and "Hydrafrac." A most educational and entertaining evening took place.

Ship Holds

Pascagoula, Miss.—The *Pascagoula* Section held its regular monthly meeting on February 4th at the Shipyard Cafe, Ingalls Yard Gate, with an attendance of 56 at the dinner and meeting. Earl S. Shulters [AWS,] U. S. Maritime Administration, introduced the visitors and speaker of the evening.

Speaker was Oliver D. Colvin, President, Cargocaire Engineering Corp., New York. Mr. Colvin spoke extemporaneously on the "Importance of Cargo Hold Conditioning." A 16-mm sound color film "Latest Jack Clamps Used in Welding" was shown in conjunction with Mr. Colvin's talk.

Mobilization Shipbuilding

Pascagoula, Miss.—The March meeting of the *Pascagoula* Section was held on the fourth at the Shipyard Cafe, Ingalls Yard Gate. Commander Frank Sandner [AWS,] Supervisor of Shipbuilding, U. S. Navy, introduced the speaker of the evening, who was Commander R. E. Ball, Senior Assistant Superintendent Ship, U. S. Navy, Pascagoula, whose subject was "Mobilization Shipbuilding."

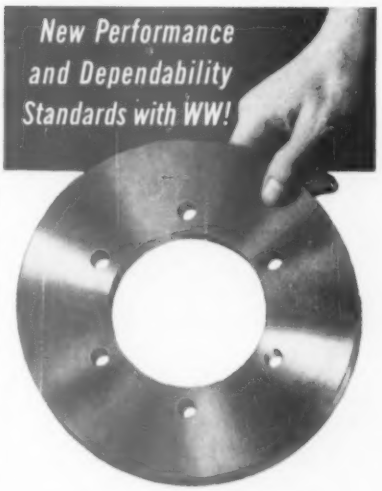
The sound color movie entitled "Metallizing" was shown through the courtesy of the Metallizing Engineering Co., Inc. Fred King [AWS,] Field Engineer, Metallizing Engineering Co., Inc., answered questions and comments from the floor after the showing of the film.

Design

Peoria, Ill.—The *Central Illinois* Section held a dinner meeting on March 18th at the Mecca. An excellent talk on the subject "Design as a Means of Controlling Distortion" was given by Omer Blodgett [AWS], of the Lincoln Electric Co. The talk was very well presented with blackboard sketches of applications and data pertinent to the subject. An interesting discussion period followed. Technical chairman for the meeting was W. H. Neptun, Factory Manager for Hyster Co.

A-C and D-C Welding

Philadelphia, Pa.—The regular monthly



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dinner meeting of the *Philadelphia* Section was held on March 16th at the Engineers Club. Speaker at the technical meeting was G. K. Willecke (AWS), Physicist for the Miller Electric Manufacturing Co. Mr. Willecke presented an interesting discussion on "Comparison of A-C and D-C Welding."

Future of Welding

Phoenix, Ariz.—The *Arizona* Section held its monthly dinner meeting at the Westward Ho Hotel on March 18th.

The speaker of the evening was T. B. Jefferson (AWS), Editor of the *Welding Engineer*, who spoke on "What the Future Holds for Welding." His talk was lucidly presented and included problems that face those who are involved with welding, whether they are welding engineers actually responsible for welding operations or those only remotely connected with the welding industry.

With his broad background of knowledge, Mr. Jefferson kept those present well interested and all agreed it was a most profitable meeting.

Aluminum Alloys

Pittsburgh, Pa.—The March 18th dinner meeting of the *Pittsburgh* Section held at Hotel Webster Hall was unusual in several important respects.

G. O. (Gus) Hoglund returned to his old hometown Section and presented a very complete and thorough discussion on "Welding and Brazing the Aluminum Alloys." He also gave a "first appearance," before any section, of the Aluminum Co.'s new sound color film "Brazing Alloy Metals." This film and slides, with his inimitable presentation of a very interesting subject, left little for the nearly 100 in attendance, to ask. Mr. Hoglund is Head of Welding Section, Alcoa Processes Department Laboratories, Aluminum Company of America, New Kensington, Pa. He is a past-chairman of the Pittsburgh Section, having served in that capacity from 1945 to 1947 as well as serving on the Executive and many other Committees.

This meeting was also the occasion for the return of six past-chairmen, Frank Bernard, E. J. W. Egger, Chas. H. Jennings (past-president of the AWS) "Gus" Hoglund (himself), Harry Schane and "Ted" Morgan.

At the dinner preceding the meeting, 47 were present and Paul Galiardi, the "Maitre-de," did himself proud with one of the best spreads ever placed before a crowd of hungry welders.

For a "Coffee Talk" Paul Barr of Williams and Co. gave a very entertaining talk on his "hobby"—collecting Currier and Ives lithographs and paintings.

Copper and Titanium Alloys

Rochester, N.Y.—An exceptionally large number turned out for the February 16th meeting of the *Rochester* Section held at the Barnard Exempt Firemen's Assn. Club. The source of this great interest was the guest speaker, J. J. Chyle (AWS), Director of Welding Research with the A. O. Smith Corp., who spoke on "The Welding of Copper and Titanium Alloys."

After giving a brief history of each, Mr. Chyle outlined the extraction and production of the metals from the ore to the commercial alloys. The group was told that titanium combines very readily with other elements and that the physical properties of titanium vary greatly with the alloy element, some of which are: Chromium, iron, manganese, aluminum, molybdenum, oxygen and nitrogen. While the method of welding recommended for titanium is the inert arc using a tungsten electrode, satisfactory welds can be made by the flash-welding and spot-welding processes, under proper conditions.

The lecture, which was excellently illustrated by slides of data tables, curves, photomicrographs, radiographs, as well as color photographs, went on to outline welding procedure for titanium alloys and the mechanical properties of the weldments of the various alloys as welded by these procedures.

For those interested in this phase of Mr. Chyle's discussion, more detail can be found in his published paper in the February issue of THE WELDING JOURNAL Research Supplement.

In outlining on the welding of copper and copper alloys, Mr. Chyle enumerated the different copper alloys and the various filler metal rods that could be used. Procedures and processes of welding were discussed, as well as the physical and mechanical properties of the weldments. Methods of inspection, and the sensitivity of these methods were outlined. Metallographic studies of the weld zones of several alloys were shown in full color.

In summary, Mr. Chyle stated that, currently, titanium can be welded with mechanical properties equivalent to the base metal. He expects to see 200,000 psi tensile specimens in the relatively near future.

A very interesting question-and-answer session followed the talk.

Annual Quiz Night

Saginaw, Mich.—An annual quiz night was held on March 12th under the sponsorship of the *Saginaw* Section. Two copies of a mimeographed questionnaire containing 22 questions were given to each person participating in the quiz. One copy was turned in;

the other copy was retained by the individual for correcting during the panel discussion. At the conclusion of the session the winner was determined by checking the corrected copy against the copy which had been turned in.

A copy of the Purdue Trade Information Test was given to each student as a "homework" assignment with the request that they be brought to the April meeting when the correct answers will be given.

Nondestructive Tests

South Bend, Ind.—The *Michiana* Section met on February 19th to learn a bit about nondestructive testing of welds from Kermit Skeie, of the Magnaflux Corp. The discussion included X-rays, supersonics, penetrants and, of course, magnetic testing. For each method of testing, Mr. Skeie outlined briefly the fundamentals of why it worked and what it showed. For ferrous welding, the workhorse is magnetic testing, and slides showed some interesting applications of this, such as prod electrodes and dry powder being used on a cross-country pipe line *in situ* and a continuous, automatic setup to test the longitudinal welds in pipe. The pipe-line job was of particular interest to this section for it was on the line which furnishes gas to South Bend.

Prior to the technical meeting, a past-chairman's pin was presented to George Mittler, who guided the section during their 1951–52 season.

Metallurgy

South Bend, Ind.—The *Michiana* Section traveled into the realm of metallurgy for their March meeting, with a talk entitled "Simplified Metallurgy for Welders and Welding Supervisors" by Anton Schaeffler AWS, Metallurgist, Welding Research Division, Allis-Chalmers Co., Milwaukee, Wis.

For mild steel welds, he said, strength and ductility are the main considerations, and by means of a simplified constitution diagram he showed why some welds are not ductile enough for code requirements and how they can be made properly.

With alloy steels, a novel T-T-T curve involving Moe and Joe on a roofing job helped explain the effects of alloying and preheating.

The use of stainless rods involves still another phase of metallurgy, and some diagrams showed how to make a first estimate of whether a given rod will successfully weld the desired base metal.

Steel Casting Repair

Springfield, Mass.—A. B. Steck, Metallurgist, G. E. Foundry Department, Everett Works, was the speaker at the technical session of the regular monthly dinner meeting held on March 10th by the *Western Massachusetts* Section. Mr. Steck presented a clear-cut, interesting talk on "Steel Casting Repair."

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Welding Metallurgy

Springfield, Mass.—The *Western Massachusetts* Section held its February dinner meeting on the 10th at Blake's Restaurant. Carl A. Keyser AWS, Associate Professor of Metallurgy, University of Massachusetts, covered some excellent material in his talk on welding metallurgy.

Structural Fabrication

Toledo, Ohio.—Ross Yarrow AWS, Consolidated Iron and Steel Co., was the speaker at the February 12th dinner meeting of the *Toledo* Section held in Linck's Cafeteria. Mr. Yarrow very ably covered the subject "Structural Fabrication."

Safe Practices

Toledo, Ohio.—The March 12th dinner meeting of the *Toledo* Section was addressed by Roland Stentz AWS, Air Reduction Sales Co. Mr. Stentz gave an extemporaneous discussion on "Safe Practices in the Use of Oxygen and Acetylene" which covered new applications and processes. A film entitled "No Finer Electrodes Made Anywhere" was shown through the courtesy of the Arcrods Co.

Schedule of Meetings

Sheffield, Ala.—Meetings of the *Tri Cities* Section are scheduled for the last Thursday of each month except for the month of November. That date would fall on Thanksgiving so the meeting was changed to December 3rd. Meeting date and speakers for the balance of the season are given below:

May 28th—F. A. Bodenheim, Jr. AWS, Federal Machine & Welder Co., Warren, Ohio

June 25th—William R. Apblett, Jr. AWS, Naval Research Laboratory, Warren, Ohio

July 30th—R. Milligan AWS, The Ocean Accident & Guarantee Corp., New York, N. Y.

August 27th—Charles Brown AWS, Eutectic Welding Alloys Corp., Birmingham, Ala.

September 24th—William J. Farrell AWS, Sciaky Brothers, Inc., Chicago, Ill.

October 29th—G. J. Strate AWS, Air Reduction Sales Co., Birmingham, Ala. (not confirmed)

December 3rd—William R. Plummer AWS, Progressive Welder Sales Co., Detroit, Mich. (not confirmed)

Future of Welding

Tucson, Ariz.—Arizona's largest and newest Section, *Tucson*, held its second meeting March 17th at Georget's Restaurant, Tucson, and had as guest speaker T. B. Jefferson AWS, Editor of the *Welding Engineer*. Mr. Jefferson presented an excellent semitechnical talk on "What the Future Holds for Welding."

Chairman Joseph A. Pruitt introduced many guests including J. L. Gayman, Shop Instructor of the Nogales High School, and Hal Savage AWS, President of the Arizona Welding Equipment Co. from Phoenix.

Industrial X-Ray

Tulsa, Okla.—Robert E. Miller, of the Greb X-Ray Co. was the speaker at the February 4th meeting of the *Tulsa* Section. Mr. Miller gave a semitechnical talk on "Industrial X-Raying" which was illustrated by slides and motion pictures.

At the dinner a film of the Gator Bowl Football Game of TU vs. FU was thoroughly enjoyed.

Automatic Welding

Tulsa, Okla.—An extemporaneous discussion by Ralph A. Trentham of the Reed Engineering Co. on the subject "Automatic Welding Fixtures" was given at the March 3rd meeting of the *Tulsa* Section.

Plant Tour

Warren, Ohio.—On October 16th the

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Mahoning Valley Section had a very interesting tour through the Packard Electric Co. plant. The tour was conducted by Carter Pickup AWS of that company and was attended by 75 members and guests.

Welding Education

Warren, Ohio.—Fifty-five members and guests were very much enthused with the speaker and the subject he presented at the November 20th meeting of the *Mahoning Valley* Section. Speaker was W. J. Heuschkel AWS whose subject was "Education for a Welding Engineer and Supervisor."

Mr. Heuschkel received his degree from Montana State College in 1929 and upon graduation served seven years in the U. S. Navy. From 1936 to 1944 he was with the U. S. Steel Corp. and since 1944 he has been with the Westinghouse Electric Corp. of whose welding section he is manager.

Radiology

Warren, Ohio.—A very successful meeting of the *Mahoning Valley* Section was held on January 15th and was attended by 58 members and guests. The speaker was J. E. Snyder whose subject was "Radiology in Tank Fabrication."

Mr. Snyder is chief metallurgist for the General American Transportation Corp. at Sharon, Pa. He is a native of the Mahoning Valley district and received his educational training in this area. He has been employed by General American for about 12 years and during this time has had the duty and responsibility of performing radiographic work to various different codes and specifications.

Aircomatic Welding

Warren, Ohio.—The February meeting of the *Mahoning Valley* Section was held on the 19th. L. W. Kunkler AWS of Air Reduction presented a lecture and movies covering the Aircomatic process of welding. This meeting was attended by approximately 55 members and guests.

Low-Hydrogen Electrodes

Washington, D. C.—The regular monthly dinner of the *Washington* Section was held on January 28th at O'Donnell's Restaurant. The technical meeting took place in the Pepco Auditorium. The subject, "Mild Steel, Low-Hydrogen and Low-Alloy Electrodes," was presented by August Clemens, Jr. AWS. Mr. Clemens is Director of Research and Welding Engineering at the Arcrods Corp. He has been connected with Arcrods since June 1940.

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Supplement to the Welding Journal, May 1953

Recrystallization Welding

Recrystallization is established as the mechanism of solid phase welding. The principal factors controlling recrystallization are discussed and related to welding. Shear strengths of welds are discussed. A basic relationship between recrystallization temperature and degree of deformation is derived and analyzed

by John M. Parks

Abstract

Recrystallization is established as the mechanism of solid phase welding. The principal factors controlling recrystallization are discussed and related to welding. Shear strengths of recrystallization welds are discussed. A basic relationship between recrystallization temperature and degree of deformation is derived and analyzed.

TO THE metallurgist, there are three basic welding processes: fusion welding, brazing or soldering, and pressure welding. In the first two, intimate metallic contact is achieved by the use of molten metal with or without a flux. Once intimate contact is produced by merging of molten metal or by wetting of solid metal by molten metal, solidification produces a continuous crystalline structure between the faying surfaces and a sound weldment is achieved. The molten metal serves two vital functions:

1. It eliminates the need for smooth faying surfaces to secure intimate metallic contact because molten metal accommodates itself to the contour of the metal being joined.
2. The molten metal, with the help of fluxes or parent metal melting, removes nonmetallic films from the surfaces being welded, thus assuring intimate metallic contact.

In pressure welding, no molten metal is present to perform these two essential functions. Some other mechanism must function to accomplish this vital need. After four years of careful study and analysis, the author has conclusively proved to himself that this mechanism is recrystallization, and that the so-called pressure welding process should be more rightly known as recrystallization welding. It is the purpose of the following paper to review briefly a bit of the extensive work on this subject by analyzing the mechanism of bonding and presenting the conditions which are required to accomplish recrystallization welding of a number of common metals successfully.

THE NATURE OF THE METALLIC BOND

Many scholars and engineers have pondered the deep mystery of the metallic state, and explored the nature of the forces that hold metal atoms together in a strong, ductile, coherent mass. The subject is a complex one inasmuch as electrical, electromagnetic and mass attraction forces are all operative simultaneously. As metal atoms approach one another, the net effect is to cause a stronger binding force until a maximum attractive force is reached; as the distance between

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Paper to be presented at the National Spring Meeting, AWS, Houston, June 16-19, 1953.

atoms is further decreased, the magnitude of this force subsides until the force between atoms becomes zero at the normal crystallographic parameters. Further lessening of distance between atoms results in enormous repulsion forces.

If two metallic surfaces were in perfect atomic registry and were absolutely flat and free from all types of surface films, they could be welded merely by bringing them together. Under no circumstances, however, can these ideal conditions be met. Perfect atomic registry is not likely because of grain orientation and the methods used for preparing metal surfaces. No surface is flat. Films cover every metallic surface experienced under normal atmospheric conditions. However, a mechanism for attaining these objectives is available; this mechanism is recrystallization.

When two reasonably clean metal surfaces are pressed together, they are held apart by the high points or projections (asperities) as described by Bowden and Tabor.[1] The effect of increased pressure over the faying surfaces is to increase the contact area by physically crushing asperities to such a bearing area that they may sustain the applied load. If the metal flows with difficulty, a relatively small contact area may sustain the entire load. If the metal possesses a low yield strength, high contact area results. Bowden and Tabor relate this real contact area, A, to the load, W, which presses a unit surface area together, and the mean yield strength, Pm, of the asperities by the expression:

$$A = \frac{W}{Pm}$$

During recrystallization, the mean yield strength of the metal approaches zero; as a result, only a relatively light load is required to establish a real contact over the entire surface.

With regard to films on metal surfaces, Smithells,[2] and more recently Dushman,[3] have summarized the knowledge on this subject very well. Most thin films on metals are supported by the metal beneath the film. If this support is momentarily relieved, such as will occur during recrystallization, the interfacial tension of the film will cause it to coalesce, thereby eliminating it as a nonmetallic barrier preventing intimate metallic contact between faying surfaces. Furthermore, during the process of recrystallization, crystal growth establishes atomic registry across faying surfaces, thereby fulfilling all three requirements for bonding solid metals without the use of molten metal.

RECRYSTALLIZATION OF METALS

Before applying recrystallization as the mechanism for achieving welding, it is first necessary to know what factors cause recrystallization, and quantitatively how they influence it. This subject, in itself, has been the topic of an ever-increasing number of technical publications. Briefly, the principal factors are composition, degree and rate of deformation, and time at temperature. Other factors such as grain size, deformation temperature and crystal orientation are so closely associated with these three principal factors, they may be considered as being dependently related to them.

In general, the less a metal crystal is contaminated with other metals and nonmetals, the lower will be its recrystallization temperature. In this regard, however, no quantitative relationship has yet been evolved. Fortunately, this quantitative relationship is not needed for an understanding of recrystallization welding if metals of the same composition are being welded to one another. It is only important when joining metals of different compositions.

In general, the greater the degree of deformation, the lower the recrystallization temperature. This qualitative relationship has been known and taught to metallurgists for many years; however, to the author's knowledge, no quantitative relationship has yet been evolved. As deformation greatly influences the temperature at which recrystallization occurs and is vital to understand recrystallization welding, a quantitative relationship between recrystallization temperature and degree of deformation was sought and found; namely,

$$\theta = A \ln \delta + B$$

where:

θ is the recrystallization temperature.
δ is the true strain produced by the deformation; that is, the logarithm of the ratio of deformed length to original length:

$$\delta = \int_{l_o}^{l} \frac{dl}{l} = \ln \frac{l}{l_o}$$

A and B are both composition and time dependent constants.

A complete discussion of this relationship and part of its metallurgical significance is given in the Appendix. Table 1 and Fig. 1 present a compilation of the data in the literature, correlated using this relationship. It should be noted that when some metals, such as aluminum, copper and silver, are deformed beyond a given degree, the recrystallization temperature is not substantially lowered by further deformation. For the purpose of discussion, the deformation at which this occurs has been called recrystallization deformation and the temperature at which it occurs, the recrystallization deformation temperature.

With regard to time, several investigators have established the time dependance to be a logarithmic relationship:

$$\frac{1}{\theta} = A \ln t + B$$

where:

θ is the recrystallization temperature.
t is the time required for recrystallization.
A and B are both composition and deformation dependent constants.

This relationship has been determined for a number of alloys; however, a compilation is not presented because it is not significant to the practical application of

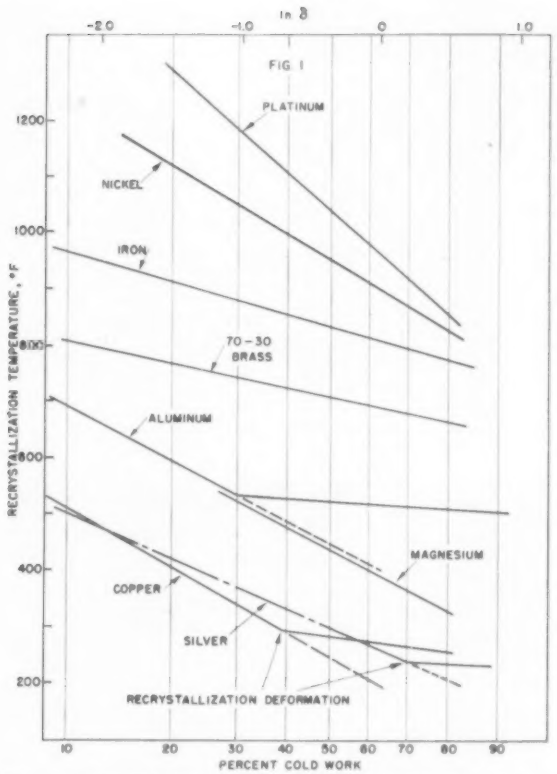


Fig. 1 Recrystallization temperature vs. degree of deformation

The relationship between the degree of deformation and the recrystallization temperature for a number of metals reported in the literature. The derivation of this relationship is presented in the Appendix.

recrystallization welding. Because the parts being welded must be brought to temperature, very short times are not practical; on the other hand, excessively long times are not desirable from the standpoint of commercial application. Consequently, the times of importance range from ten seconds to ten minutes. Such time variations do not alter most recrystallization temperatures much more than 100° F. For short times, thermal gradients across sheet materials can be of this order of magnitude, and consequently more than offset slight variations in recrystallization temperature.

RELATION BETWEEN RECRYSTALLIZATION TEMPERATURE AND RECRYSTALLIZATION WELD STRENGTH

To establish that recrystallization is the basic mechanism of bonding and correlate it to bond strength, a series of experiments was performed on a number of sheet metals. Using $^1/_{16}$-in. sheet, whose surface had been diamond scraped or milled with a steel cutting edge—for the purpose of removing surface films and severely deforming the surface layers—a number of specimens were welded by pressing the faying surfaces together between heated circular dies held at various temperatures (Fig. 2). To assure physical contact, yet prevent severe interfacial deformation, die indentations were held to between 5 and 10% of the sheet thickness. By maintaining a bonding diameter-sheet thickness ratio of less than three to one, shear type failure could be effected in lap specimens made at various temperatures, thereby permitting determination of the true shear strength of the interfacial metal.

The results of this study are presented in Fig. 3 and Table 2. On raising the temperature, no bonding is achieved until a discrete temperature is reached. Higher temperatures do not increase the shear strengths of the welds. This shear strength does not tend to increase when increasing welding temperatures beyond the initial bonding temperature; its magnitude is that of the annealed metal as shown by a compilation of data from the literature, Table 3. Some comparable

Table 1—Recrystallization Data of Several Common Metals

Metal	*—Degree of strain— % cold work*	*ln δ*	*Recrystallization temperature, °F*	*References*
Aluminum (28)	10	−2.25	685	4
	20	−1.50	602	4
	30	−1.03	530	4
	60	−0.088	510	4
	80	+0.476	505	4
Aluminum (28)	20	−1.50	585	ARF* Determination
	40	−0.672	530	"
	60	−0.088	520	"
	80	+0.476	510	"
Copper	3	−3.49	720	5
	10	−2.25	510	5
	25	−1.245	365	5
	50	−0.367	280	5
	67	+0.104	265	5
	93	+0.978	190	5
Iron	5	−2.965	968	6
	10	−2.25	950	6
	50	−0.366	847	6
	75	+0.328	770	6
Magnesium	28	−1.113	527	7
	36.5	−0.79	482	7
	52	−0.31	437	7
	62	−0.033	392	7
	74	+0.298	347	7
Nickel	10	−2.25	1157	8
	30	−1.03	1060	8
	50	−0.366	968	8
	70	+0.185	878	8
	82	+0.54	780	8
Platinum	19	−1.56	1265	9
	39	−0.70	1130	9
	50.8	−0.34	1040	9
	60	−0.088	968	9
	80.5	+0.49	842	9
	89.5	+0.81	680	9
Silver	11	−2.15	482	10
	29.2	−1.06	383	10
	55.7	−0.21	266	10
	82.5	+0.54	230	10
	6	−2.82	555	11
	16.5	−1.71	527	11
	21	−1.43	495	11
	40.5	−0.65	473	11
	60.5	−0.07	428	11
	75	+0.33	392	11
	80.1	+0.48	392	11
	95	+1.10	383	11
70-30 Brass	10	−2.25	800	12
	25	−1.245	752	12
	75	+0.328	662	12

* ARF–Armour Research Foundation.

Table 2—The Relationship Between Welding Temperature and Weld Shear Strength for a Number of Common Sheet Metals, 1/16 in. Thick, Welded with 1/8 In. Heated Dies

Metal	*Interfacial temperature, °F*	*Shear load, lbs*	*Weld diameter, in.*	*Shear strength, psi*	*Comments*
Electrolytic copper	250	30	0.16	1,500	
	250	10	0.165	470	
	250	10	0.170	440	
(15 Mins bonding time)	302	292	0.140	19,000	
	302	228	0.130	17,100	
	302	290	0.130	21,800	
	340	240	0.120	21,200	
	340	200	0.120	17,700	
	340	262	0.115	25,200	
	340	278	0.120	24,600	
	340	298	0.135	20,800	
	400	456	0.185	17,000	
	400	420	0.160	20,900	
	400	410	0.160	20,400	
70–30 Brass	500	—	—	—	No bonding
	550	340	0.13	25,600	
	550	472	0.145	28,600	
(2 Mins bonding time)	600	362	0.120	32,000	
	600	444	0.140	28,800	
	600	386	0.125	31,400	
	650	548	0.145	33,200	
	650	504	0.150	28,500	
	700	681	0.180	26,800	
	700	626	0.165	29,200	
	700	582	0.165	27,200	
	750	774	0.185	28,800	
	750	786	0.195	26,300	
	750	714	0.190	25,100	
	800	578	0.170	25,400	
	800	584	0.170	25,700	
	800	586	0.170	25,900	
SAE 1020 steel	730	—	—	—	No bonding
	800	692	0.155	36,600	
	800	660	0.15	37,100	
(2 Mins bonding time)	800	614	0.14	39,900	
	815	618	0.150	41,200	Also 2 samples did not bond
	815	662	0.135	49,000	
	830	276	0.100	35,200	Also 5 samples did not bond
	830	641	0.155	34,000	
	900	648	0.155	41,800	
	900	580	0.15	32,800	
	900	581	0.14	37,800	
	900	688	0.15	38,900	
	950	638	0.165	29,800	
	950	590	0.155	31,200	
	950	454	0.135	31,800	
28 Aluminum	415	—	—	—	Spotty bonding
	461	202	0.14	13,100	
(15 Mins bonding time)	461	212	0.135	14,800	
	470	196	0.14	12,700	
	517	231	0.17	10,200	
	517	244	0.1825	9,400	
28 Aluminum	280	—	—	—	No bonding
	357	108	0.105	12,500	
(1 Min. bonding time)	357	155	0.13	11,750	
	400	220	0.185	8,200	
	435	182	0.175	7,600	
	435	194	0.175	8,100	
	475	261	0.20	8,300	
	475	244	0.20	7,800	
Silver clad aluminum	205	—	—	—	No bonding
	280	144	0.145	8,700	
(1 Min. bonding time)	357	302	0.14	19,600	
	400	314	0.16	15,600	
	435	324	0.165	15,100	
	470	570	0.18	22,400	
75A Titanium	900	—	—	—	No bonding
	975	250	0.0825	46,800	
(2 Mins bonding time)	1000	1040	0.150	59,000	
	1000	972	0.140	63,100	
	1040	550	0.145	33,400	
	1065	434	0.130	32,600	
	1065	1174	0.145	71,200	
130A Titanium	975	—	—	—	No bonding
	1000	—	—	—	No bonding
(2 Mins bonding time)	1020	620	0.08	123,000	
	1065	1023	0.10	131,000	
	1075	1198	0.11	126,000	

Table 2 (*Continued*)

Metal	*Interfacial temperature, °F*	*Shear load, lbs*	*Weld diameter, in.*	*Shear strength, psi*	*Comments*
Silver	160	—	—	—	No bonding
	215	56	0.18	2,200	
(15 Mins bonding time)	215	82	0.175	3,400	
	215	34	0.18	1,340	
	250	214	0.175	8,900	
	250	304	0.175	12,600	
	321	321	0.1825	12,450	
	321	347	0.18	13,600	
Soft lead	146	42	0.18	1,650	
	166	44	0.18	1,730	
(2 Mins bonding time)	200	32	0.145	1,940	
	232	46	0.20	1,470	
	295	48	0.19	1,670	
	300	38	0.13	2,860	
	300	36	0.14	2,340	

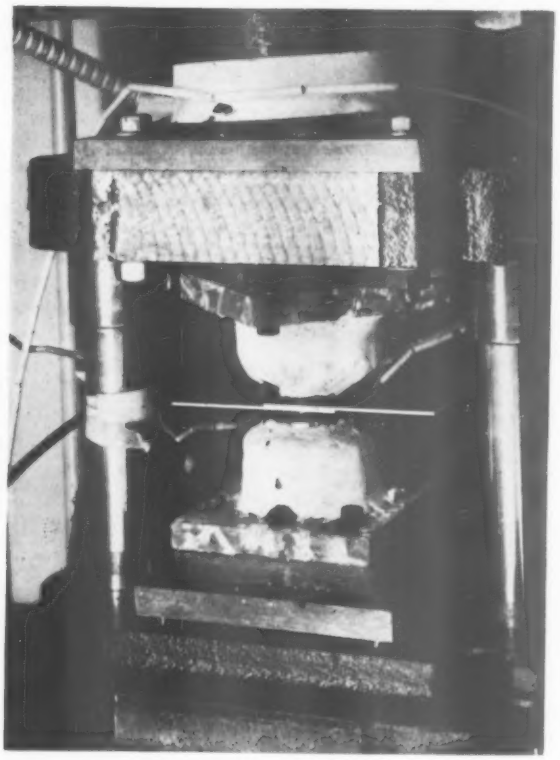


Fig. 2 An experimental recrystallization welding apparatus

Nichrome wound heaters, mounted in a die set, supply heat to steel pressing dies having a contour similar to spot-welding electrodes. By measuring interface temperatures for a test coupon and relating it to die temperatures, it is possible to standardize a set of welding conditions, wherein a set of coupons can be bonded at a given interface temperature.

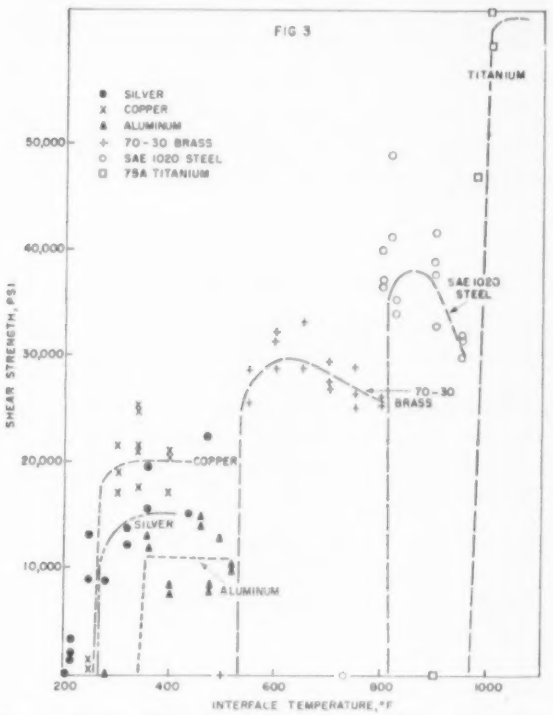


Fig. 3 Recrystallization temperature and resulting shear strength

The shear strength as a function of bonding temperature for a number of common metals reveals that the temperature at which bonding commences corresponds to the recrystallization temperature of the faying surface.

shear values have also been determined by a simulated shear test coupon, Fig. 4; however, this test coupon has not been adequately evolved to warrant a technical appraisal at present.

Comparison of Figs. 1 and 3 reveals that for each metal the discrete temperature of bonding is the recrystallization temperature of severely deformed stock of that metal. Recrystallization as the mechanism of effecting welding is hereby conclusively established.

Table 3—Comparison of Shear Strengths of Various Metals

Meta	*Shear strength, psi* — *Spot welds*	*Recrystallization welds*	*Shear test data*
Silver	—	12,900	—
Copper	—	20,000	22,000[14]
Aluminum	8,800[13]	11,000	9,500[14]
Brass (70–30)	26,500[15]	29,000	33,000[14]
SAE 1020	40,750[16]	36,000	57,300[17]
Titanium	158,000[18]	60,000	above 75,000[18]
Lead	—	1,950	1,825[14]

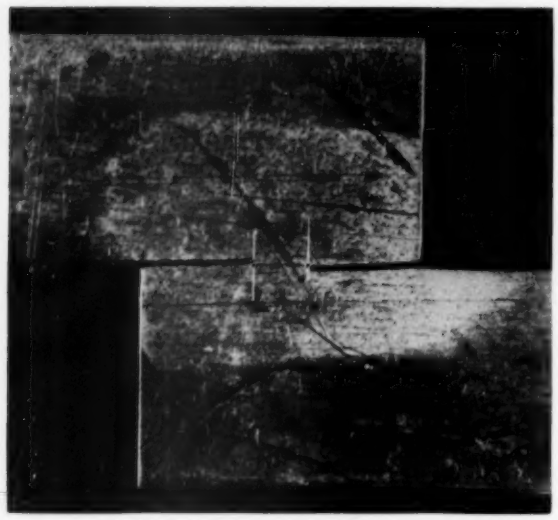


Fig. 4 A shear strength test coupon

A special test coupon designed to give an idea of the shear strength of the sheet material being bonded. When cold worked sheet is tested, the test area is recrystallized by heating it for a short time between properly heated dies. Although this test is open to some criticism, such as failing to account for crystal orientations and laminations related to rolling direction, it does give data of relative value for the material under study.

SURFACE PREPARATION

Fundamentally the methods used for surface preparation should clean the surface and establish therein the lowest possible recrystallization temperature. This means removal of all oil, grease, dirt, scale and oxide, and some means of severely deforming the surface without excessively heating it.

Dirt grease and foreign matter may be removed chemically or by solvent cleaning. This is the first step if recrystallization welding is to be successfully used commercially; it has been shown that residual grease or oil, such as a fingerprint, completely prevents recrystallization welding. Of all methods of inducing preferential cold work in the surface layers of a sheet, machining is the most effective. Scraping, turning and milling are the common methods employed to date in the laboratory. Wire brushing is also successful but is subject to variation related to the operator; namely, brush pressure and travel speed. Furthermore, brush maintenance proves some problem if the brush tends to pick up metal particles in excessive amounts. If proper care is not exercised, wire brushing will excessively heat the metal being brushed to such a temperature that recrystallization, and excessive oxidation and film formation, which is detrimental to recrystallization welding, will result.

Shot peening, if properly performed, will be effective as a surface preparation method; however, undue surface roughening often minimizes its effectiveness. Sand blasting is not desirable in that excessive amounts of foreign matter are often embedded in the surface of the metal; for the same reason, abrasive grinding and polishing are not satisfactory.

Chemical cleaning, etching, pickling and the like are effective in removing grease, dirt and other films. However, they do not work the surface of the metal and thereby achieve low recrystallization temperatures. As a result, they are of little interest in themselves; some subsequent surface treatment must also be employed. This is illustrated in the recrystallization welding of silver clad aluminum, Table 4.

Table 4—Data on Recrystallization Welding Silver Clad Aluminum

Interfacial welding temperature, °F.	*Shear strength of nitric acid cleaned specimens, lbs*	*Shear strength of diamond scraped specimens, lbs*
Room temperature	0	0
200	20	450
300	35	(1350)*
400	45	(1950)†
500	90	(1650)†

* Failure occurred at silver-aluminum clad interface.
† Failure by tearing in the sheet.

In this series of tests, $^1/_{16}$-in. thick sheet was bonded over a one inch in diameter area in a lap type joint and tested in tension. No bonding occurs at room temperature. Diamond scraped sheet bonds significantly at 200° F and completely at 300° F whereas chemically cleaned material is bonded only at local points, wherein deformation by crushing asperities has been sufficient to cause recrystallization. The gradual increase in strength attained with chemically cleaned, silver clad aluminum is predicted by Fig. 1.

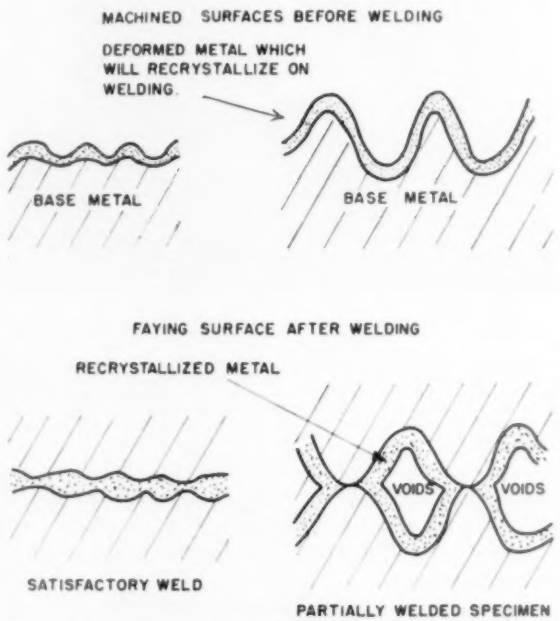


Fig. 5 Effect of surface roughness on recrystallization welding

The relationship between the depth of groove and depth of deformation, induced during a machining operation, for satisfactory recrystallization welding. If the depth of groove is much greater than the depth of surface-deformed metal which will recrystallize on welding, only partial welding with voids between welded points will result.

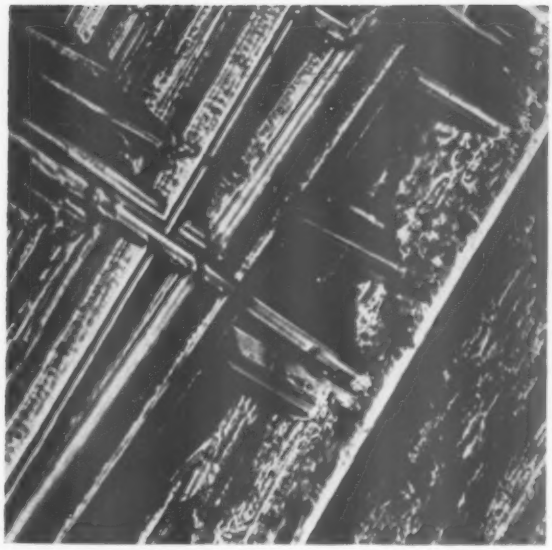


Fig. 6 Photomicrograph of a scraped 2S-½H aluminum surface prepared with a rough diamond edge, 500 ×

This surface is typical of the rough surface for which data are reported in Fig. 11. Cross-scraping is generally employed. The long continuous lines are the bottoms of the grooves.

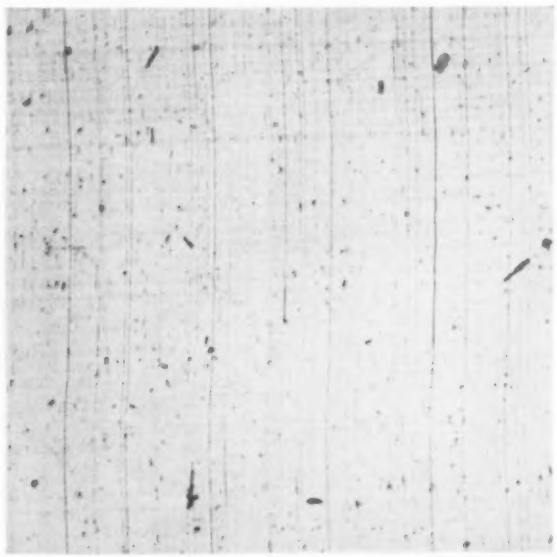


Fig. 7 Photomicrograph of a scraped 2S-½H aluminum surface prepared with a polished diamond edge, 500 ×

The very fine spots are metal inclusions; the larger dark areas are places where larger inclusions have gouged the metal. The long scratches are related to dragging of inclusions which become attached to the cutting edge during scraping.

At higher temperatures, more asperities are welded because less deformation of the asperity is required for recrystallization, the higher the temperature. As a result, more of those asperities which acquire lesser deformations during pressing, recrystallize and bond as higher temperatures are used

Fig. 9 A double-action welding jig

This double-action recrystallization welding jig was used for "deformation recrystallization welding" studies. In operation, two specimens are inserted between the heated bosses, one inch in diameter (resistance heating coils are not shown), the press in which this jig is mounted is then closed, thereby applying pressure on the bosses by compression of the eight springs located symmetrically about the bosses. At full boss pressure, the plungers, made of various lengths of ⅛-in. drill rod, make the desired indentation. By controlling their length, the percentage indentation can be controlled accurately.

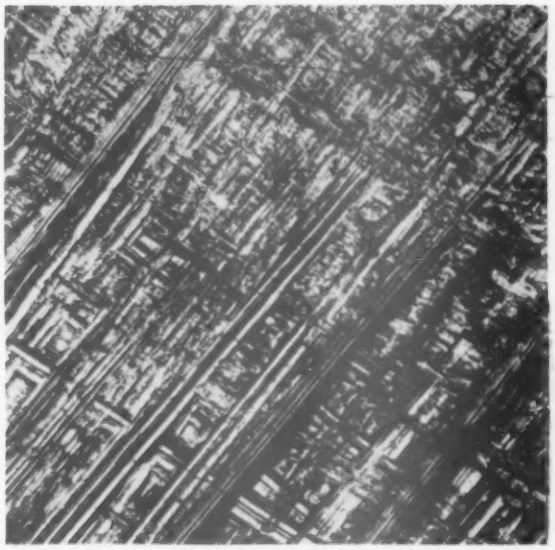
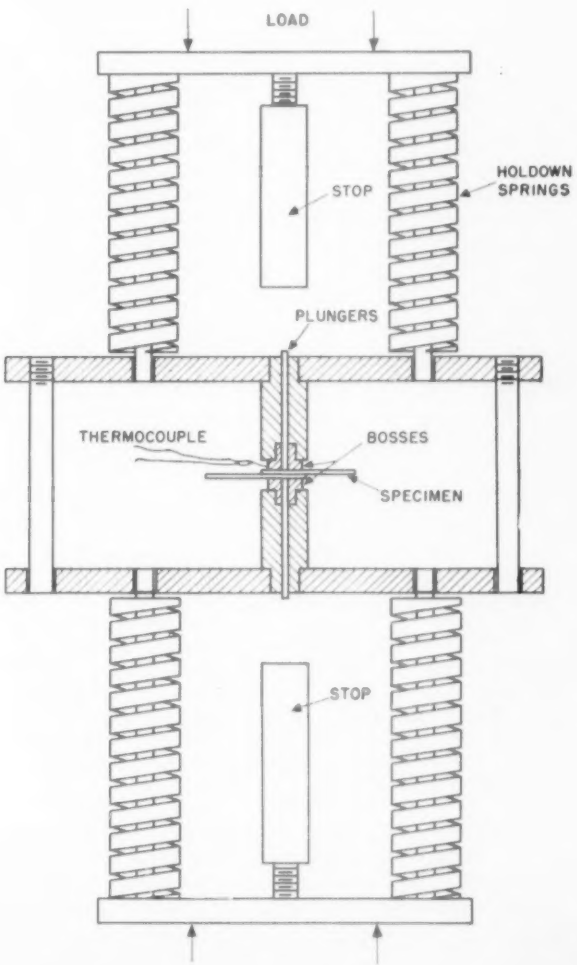


Fig. 8 Photomicrograph of a 2S-½H aluminum surface prepared by scraping with a rough ground diamond edge, welding and then twisting apart to show the welded areas, 100 ×

Only a relatively small percentage of the total interfacial area is bonded.



Surface roughness of machined surfaces is an important factor which must also be considered. The depth of deformed metal must be sufficient to permit intimate metallic contact during recrystallization. If the roughness is such that the depth of grooves is greater than the depth of deformed metal, intimate metallic contact cannot be maintained over the entire area. This is illustrated in Fig. 5.

Figures 6 and 7 show typical diamond scraped surfaces made using a rough and smooth ground diamond tool. The rough ground surface is not as satisfactory as the smooth ground surface; the rough surface is not completely bonded. Figure 8 shows a rough surface which was bonded and then twisted apart; the deep grooves were never in contact, hence, bonding conditions are unsatisfactory because of roughness.

RECRYSTALLIZATION WELDING BY DEFORMATION

Recrystallization welding below the recrystallization temperature of the surface metal can only be achieved if the surface layers are severely deformed at the same time they are brought into contact. This is indicated by Fig. 1. For example, if surface machined 2S aluminum is bonded isothermally at room temperature, Fig. 1 would indicate that it would have to be deformed beyond 95%. However, working the metal produces heat, in the case of 2S aluminum probably 500° F is attained on the slip planes, if heavy deformations are made, as indicated by Fig. 1. As a result, deformation of the order of over 30% (the recrystallization deformation) is probably the minimum required for bonding at room temperature.

If the metal is heated during welding, the degree of deformation required for a given degree of bonding is less. This is illustrated by experiments using a double acting recrystallization welding jig, Fig. 9. Two sheets are inserted between heated dies and two bosses grip the sheet as the press closes. After building the pressure up on the two bosses, two plungers press a circular indentation into the sheet. By controlling the depth of indentation, the flow of metal at the faying surfaces may be controlled. Because the exact proportionality between the two is not concise, the percent indentation serves only as an index of the percent deformation introduced into the surface layers.

The amount of deformation is also influenced by the surface roughness of the specimen. This deformation effect is illustrated in Figs. 10 and 11 which present data on welding 2S aluminum at room temperature and at 300° F. Hold down pressure is not particularly significant, if such pressure does not produce extrusion of the sheet between the hold down bosses. At 40% indentation, a 300 to 400 pound breaking load can be acquired; whereas at room temperature, 40% indentation will produce only about a 200 pound breaking load. One word of caution must be made with regard to interpreting breaking loads of specimens made with this apparatus because asperity bonding occurs under the bosses. This tends to increase the breaking load more than the real value in the deformation area. Often specimens bonded with less than 50% indentation, may be snapped apart by peeling, although in tension they exhibit substantial breaking strengths.

All of these bonding strengths are very low compared with bonding above the recrystallization temperature.

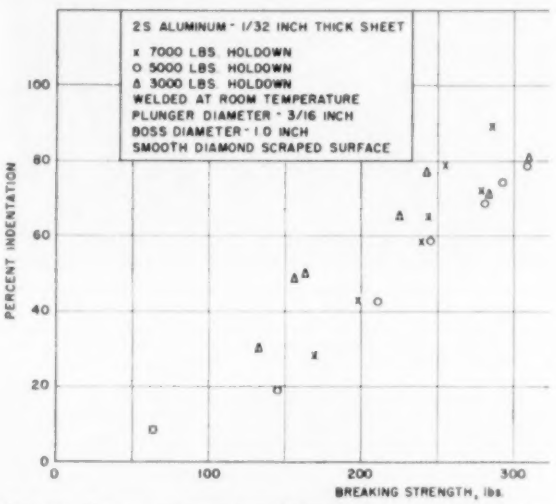


Fig. 10 Room temperature deformation recrystallization welding data

The effect of percent indentation on strength of welds made at room temperature is to increase the weld strength in a roughly proportional relationship. Below the recrystallization temperature of the metal in the faying surface, it is necessary to deform severely the metal to cause deformation recrystallization welding, and to acquire strengths comparable to thermal recrystallization welds, Table 2.

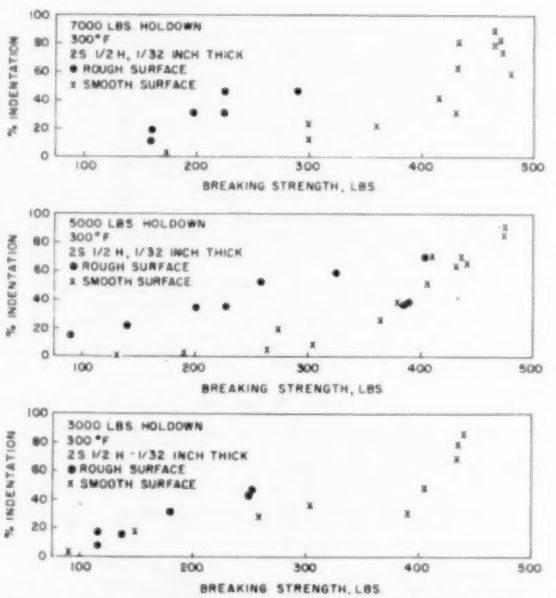


Fig. 11 Deformation recrystallization welding at 300° F

The effect of percent indentation on strength of welds made in 2S aluminum at 300° F is to achieve higher strengths than for those made at room temperature. Compared with room temperature, less deformation is required to achieve equivalent weld strengths; however, these deformation recrystallization welds are not as good as the thermal recrystallization welds, Table 2.

This is apparent by examination of fracture surfaces; even though deformation is considerable, some areas remain unbonded until the indentations become very large, such as 80%. At such deformations, small buttons are pulled out of the sheet because of the severe reduction in cross-sectional area, and consequently the breaking loads are very small. As a result, it can be concluded that "deformation recrystallization welding," wherein recrystallization is achieved by deformation, is not a commercially applicable process compared with "temperature recrystallization welding," wherein recrystallization is achieved by heating to the recrystallization temperature of the faying surface metal.

SURFACE STABILITY

The stability of a surface prepared for recrystallization welding depends upon the reactivity of the metal for the ingredients in air and the nature of the film formed. Metals like aluminum, magnesium and titanium are very reactive whereas metals like copper and silver are not.

Without exception, water vapor in the air is the most influential factor influencing the weldability of the reactive metals. The most positive proof of this influence is the very detrimental effect produced upon the recrystallization welding characteristics of 2S aluminum if it is water dipped and air dried just prior to welding. On the other hand, water and particularly water containing acids—like hydrochloric acid on copper and nitric acid on silver—have relatively little influence on weld strength.

The time after surface preparation has an influence. Figure 12 shows the gradual drop in weld strength with 2S aluminum on standing in air before welding. This drop in strength is related to development of heavier oxide films on standing.

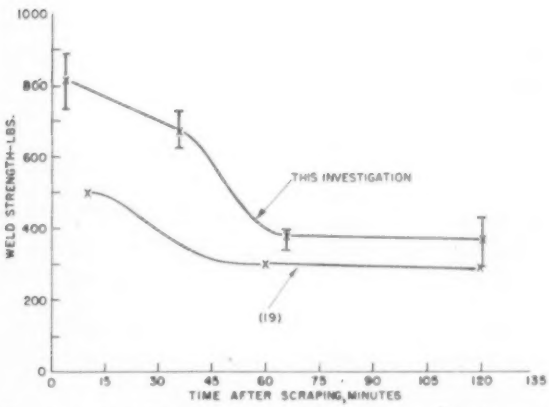


Fig. 12 The influence of elapse time between scraping and welding

The effect of the time interval between scraping and welding is to gradually lower weld strength. The tests used in this study were made on 1/16-in. 2S aluminum sheet, diamond scraped and welded at 500° F using flat 1/4-in. diameter dies and a 5000-lb load. Under these conditions, indentations from 0 to 1.6% result. The data taken from the literature were for welds made under entirely different conditions; they are presented only for the purpose of showing the similarity in strength variation with time and should not be used to correlate weld strength with values in this report unless all welding conditions are taken into consideration.

CONCLUSIONS

In summary, the following conclusions are evident:

1. The basic mechanism of solid phase welding is recrystallization..
2. The most important recrystallization relationship, necessary to the understanding of recrystallization welding, is that relating the recrystallization temperature to the degree of deformation. This relationship has been derived and applied to recrystallization welding.
3. The importance of clean, cold worked surfaces for recrystallization welding is emphasized.
4. The shear strengths of recrystallization welds are equivalent to those of spot welds, and are in agreement with the shear strengths of annealed metals.

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Appendix

THE INFLUENCE OF THE DEGREE OF DEFORMATION ON THE RECRYSTALLIZATION TEMPERATURE

The fundamental mechanism causing recrystallization is not established although there are several postulates concerning it. As yet, no explicit relationship relating quantitatively the dependence of recrystallization temperature upon the deformation has been evolved. Metallurgists have been content to observe that the greater the degree of deformation, the lower will be the recrystallization temperature, and have contended that the many variables involved defy statistical analysis of the limited data available. Such factors as grain size and crystal orientation, alloy components and impurities, rate of deformation, and deformation temperature are but a few of the experimental variables which are often cited as obstructions to an empirical analysis of experimental data.

Table 5—Latent Energy Absorbed in Metals During Extension[21]

Metal	Sample number	Extension, %	True strain	Latent energy, U cal/g
Polycrystalline copper	91	7.66	0.074	0.0165
		12.67	0.119	0.0331
		17.45	0.161	0.0524
	92	7.78	0.075	0.0221
		13.63	0.128	0.0442
		19.90	0.182	0.0727
	93	8.76	0.0842	0.0285
		15.35	0.143	0.0552
		20.20	0.184	0.0764
Polycrystalline aluminum	96	11.12	0.106	0.0165
		16.88	0.156	0.0285
		23.06	0.208	0.0423
	97	10.41	0.0993	0.0202
		16.70	0.155	0.034
		21.95	0.198	0.0451
	98	9.16	0.1379	0.0138
		15.91	0.148	0.0248
		21.88	0.198	0.0358
Aluminum single crystals	99	14.58	0.136	0.0083
		24.10	0.216	0.0138
		35.25	0.302	0.0239
		43.20	0.3595	0.0331
		52.72	0.452	0.0441
	100	16.19	0.1492	0.0083
		25.75	0.229	0.0175
		37.70	0.320	0.0294
		46.52	0.3825	0.0377
		55.72	0.443	0.0479

Yet most are agreed there must be some relationship; they cite as a concept the observation that the more a metal is deformed, the more latent energy will be stored in the metal, and contend that it is this energy which activates recrystallization. Beyond this, there is little common ground. Little is certain as to how latent energy stimulates recrystallization. In fact, some maintain recrystallization is a nucleation and grain growth process; others maintain it is merely a recovery and grain growth process. Because the structures are too small to observe under the microscope or by means of electron metallography, the running debate continues, each side losing or gaining converts as each tid-bit of fact is uncovered. With this as a background, the author has a great hesitancy to add to the din; nevertheless, the necessity of approaching the problem directly demands it.

ENERGY CONSIDERATIONS

Before considering a physical picture of what happens during deformation and recrystallization, it is first desired that an analysis of the latent energy be considered. When a metal is cold worked, energy is consumed; most of the energy is converted into heat but a small frac-

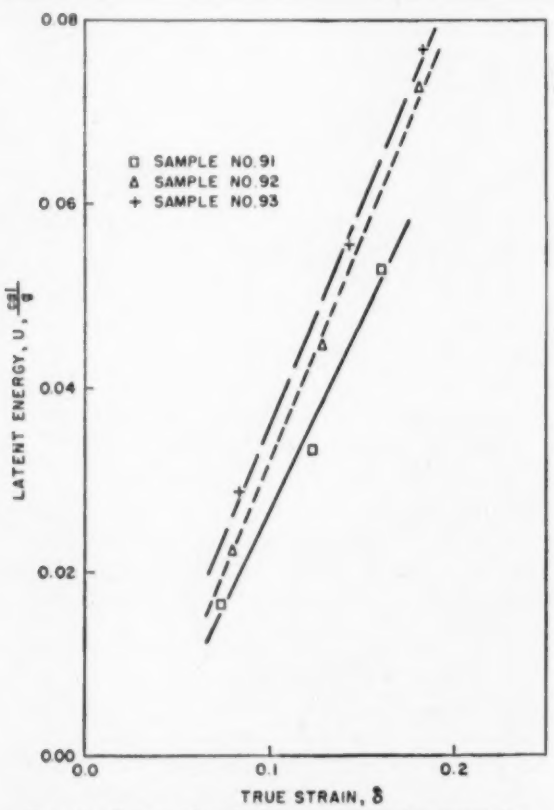

Fig. 13 Energy absorbed in copper during extension

A linear relationship exists between the latent energy absorbed and the true strain produced during deformation. Extrapolation of this relationship indicates that an initial straining can occur prior to any latent energy absorption. This is probably related to the ability of annealed crystallites to recover more rapidly than those crystallites already possessing some distortion.

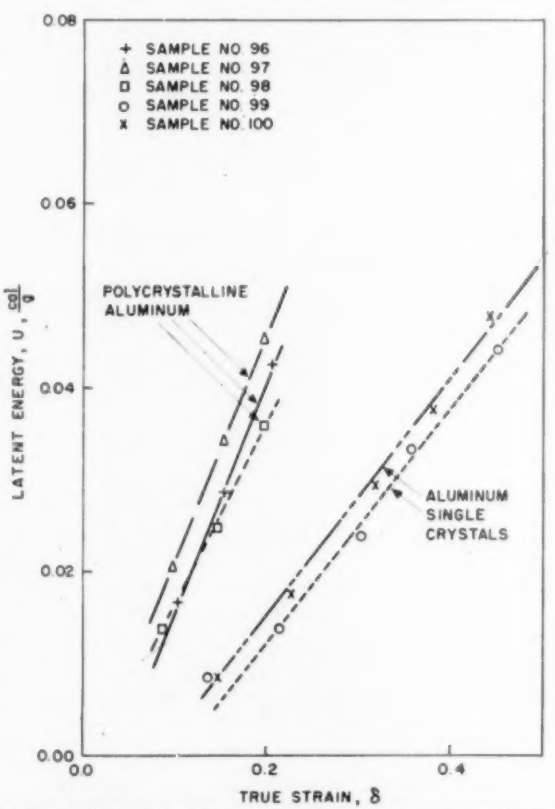

Fig. 14 Energy absorbed in aluminum during extension

The same general relationship between latent energy absorbed and true strain as found for copper also holds for aluminum. The slope of this relationship for single crystals is less than for polycrystalline material. This is probably an effect of grain size; theoretically fine-grained metals have more grain boundaries in which latent energy can be absorbed.

tion is stored within the metal[20]—this latter energy is known as the latent energy of deformation. Accurate data on the quantity of this energy retained in cold-worked metal are very limited.

In an extensive search of the literature, only one paper[21] was found to be of interest. Fortunately the data given in this paper appear to be reasonably accurate; that is, they are in excellent agreement with the concept that the latent energy is linearly related to the true strain of deformation—as shown by a plot of the data, Table 5, taken from this work of Farren and Taylor, Figs. 13 and 14. This work reveals, as conclusively as the accuracy of the data permits, that the latent energy of cold work follows the expression:

$$U = a\delta + B \qquad (1)$$

where:

U is the latent energy (cal./g.) introduced into a metal by cold work

δ is the true strain; $\delta = \int \frac{dl}{l}$

a is a material constant

B is a material constant, which probably is zero for those metals fully recovered but not recrystallized.

With regard to latent energy, the author has postulated that it is of two types: namely, energy of crystal distortion, B, which is released by recovery, and crystal boundary absorbed energy, V, which cannot be released by recovery but is released by the process of recrystallization. Considering this assumption, equation (1) becomes:

$$V = a\delta \qquad (2)$$

The value, V, for a given degree of deformation is constant at a given temperature but would be expected to vary as a function of temperature because the physical distortion of atoms in a crystal lattice should permit a greater specific heat than atoms in an undistorted crystal in much the same manner that the specific heat of a crystal or solid metal is less than that of its liquid. As a first approximation, consider this change in energy to be proportional to the absolute temperature; namely:

$$V = a\delta T \qquad (3)$$

where: T is the absolute temperature, °K.

To assist in visualization, this concept is illustrated in Fig. 15. Q is the total energy required to activate recrystallization. The various straight lines give the latent energy, V, in the metal at the various temperatures for certain degrees of deformation. At room temperature, this energy is that introduced by rolling at room temperature; as the temperature is raised, this energy increases, the rate of increase being proportional to the true strain of deformation. When this value reaches that energy, Q, required for recrystallization, recrystallization occurs and the temperature indicated by the intersection of the straight line and the Q value is the recrystallization temperature.

From this concept, the relationship between recrystallization temperature and deformation may be derived.

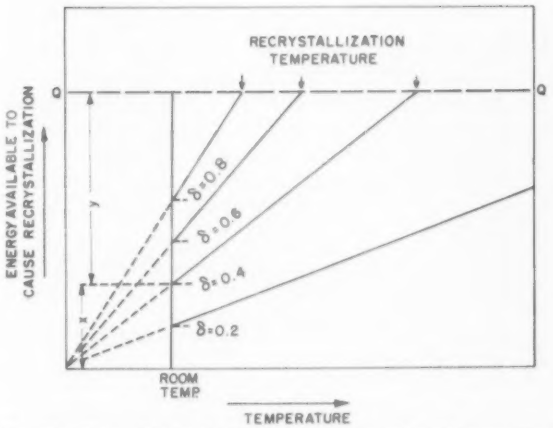

Fig. 15 The relationship between recrystallization energy, degree of deformation, and recrystallization temperature

This visualization presents the assumptions upon which the derivation of the expression:

$$\theta = -A \ln \delta + B$$

is based. X represents the latent energy introduced into the metal by deformation, and Y is the latent energy acquired when this deformed metal is heated. When the sum of these two energies reaches the value, Q, required to activate recrystallization, recrystallization occurs.

At recrystallization, the energy, Q, is achieved in the metal from two sources, the energy of true strain, X, introduced into the metal by rolling at a given temperature, and the energy, Y, in the metal by virtue of its temperature in excess of the deformation temperature:

$$Q = X + Y \qquad (4)$$

Differentiating with respect to temperature, we have:

$$\frac{dQ}{dT} = 0 = \frac{dX}{dT} + \frac{dY}{dT} \qquad (5)$$

From equation (2), it follows that:

$$\frac{dX}{dT} = \frac{dV}{dT} = a\frac{d\delta}{dT} \qquad (6)$$

From equation (3), it follows that:

$$\frac{dY}{dT} = a\delta \qquad (7)$$

Hence, equation (5) becomes:

$$a\frac{d\delta}{dT} + a\delta = 0 \qquad (8)$$

or

$$dT = -\frac{A\,d\delta}{\delta} \qquad (9)$$

or

$$\theta = -A \ln \delta + B \qquad (10)$$

The plot of the available data, Table 1, is presented in Fig. 1.

STRUCTURAL CHANGES DURING COLD WORK AND RECRYSTALLIZATION

Even though a relationship between recrystallization temperature and deformation has been derived and established, it is most important that a physical picture of changes during deformation and recrystallization be

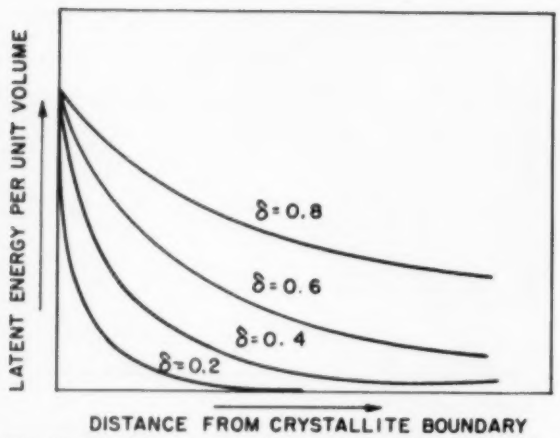

Fig. 16 The latent energy distribution within a crystalline on deformation with no recovery considered

Because of the nature of microforce distribution during the process of deformation, crystallite boundaries should receive the greatest deformation with the interior of the crystallite receiving progressively less deformation, the greater the distance from the crystallite boundary. This visualized diagram represents one concept of deformation distribution as reflected in latent energy absorption where recovery by dislocation movement is assumed to be completely suppressed.

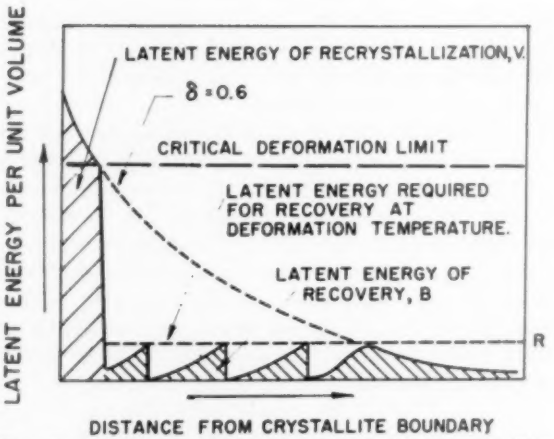
LATENT ENERGY PER UNIT VOLUME
LATENT ENERGY OF RECRYSTALLIZATION, V.
δ=0.6
CRITICAL DEFORMATION LIMIT
LATENT ENERGY REQUIRED FOR RECOVERY AT DEFORMATION TEMPERATURE.
LATENT ENERGY OF RECOVERY, B
R
DISTANCE FROM CRYSTALLITE BOUNDARY

Fig. 18 Latent energy distribution within a crystallite where recovery is proceeding simultaneous with deformation

This visualized energy distribution is a much better estimate of actual latent energy distribution existing within the crystallite during deformation. As shown in Fig. 17, the area under the latent energy distribution curve before it reaches the critical deformation limit is the latent energy of recrystallization, *V*. During deformation of many metals, recovery is occurring simultaneously with deformation. When the latent energy of recovery reaches a critical value, *R*, recovery occurs and distortion energy is released as heat. As a result, a cyclic pattern of distortion and absorbed recovery energy is found as one proceeds away from the crystallite shell. The average energy, *B*, so retained has been neglected in the derivation of the recrystallization temperature-deformation relationship as this energy does not contribute to activation of recrystallization.

presented. This visualization may be disputed; nevertheless, it is presented in the hope that, if incorrect, it will stimulate others into further creative efforts in spite of the lack of adequate experimental tools.

When a metal is deformed, the metal crystal shears or locally flows in certain selected areas which are related to the direction of the forces causing deformation. Within the areas of local deformation, shear occurs in directions related to crystal structure. The over-all result is a fragmentation of the grains into smaller crystallites, surrounded by severely deformed envelopes. Within the crystallite so formed, a certain lattice distortion is produced which, in time, may be relieved by dislocation movements, such a process being spoken of as recovery. At the boundary of the crystallite, an envelope or shell of heavily distorted metal is created, in which no dislocation movement is possible because the degree of distortion is beyond the critical amount permissible for dislocation movement.

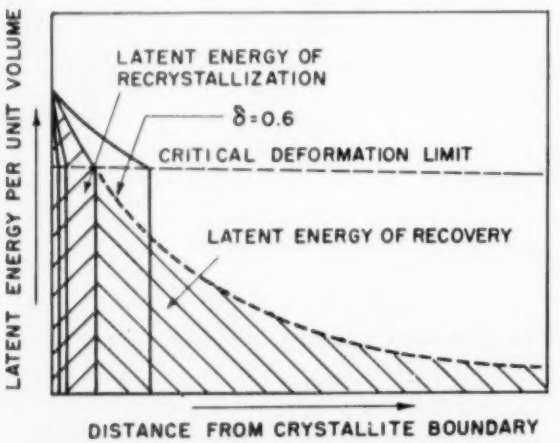

Fig. 17 Latent energy distribution within a crystallite after deformation and recovery

In the crystallite shells, atomic disarrangement becomes so severe that dislocation movement can no longer occur; the limit at which this occurs is noted as the critical deformation limit. The area under the latent energy distribution curve before it drops to this limit is the latent energy, *V*, retained within the crystallite which is released during the process of recrystallization. The remaining area under this curve is the energy released by recovery, provided no recovery has occurred during deformation.

With regard to the latent energy, U, it is stored in two parts:

V, energy stored within the shells.
B, energy stored in lattice distortion.

Figure 16 represents a visual concept of this energy distribution for various deformations. After recovery, this energy distribution is as shown in Fig. 17; the energy within the shell is essentially unchanged, whereas the energy within the crystallite is released as heat. Actually, recovery may occur during deformation; hence, the latent energy distribution is as shown in Fig. 18.

In the initial stages of deformation, crystallite size is refined by fragmentation; during the process of deformation, the thickness of the crystallite envelop increases and the diameter decreases until a point is reached at which the crystallite radius is equal to the thickness of the crystallite shell. At this point, very little additional energy can be retained in a metal. The deformation at which this occurs is the recrystallization deformation, indicated in Fig. 1 by the change in slope from the $\theta = -A \ln \delta + B$ relationship to a near horizontal line.

Below the recrystallization deformation, recrystallization occurs by growth. Nuclei are not required inasmuch as fully recovered crystallite cores are available for growth. Above the recrystallization deformation, recrystallization is a nucleation and growth phenomena. Such a concept may explain the reason for

controversy in this regard. Depending upon conditions, each side in the dispute may cite data to prove the mechanism of its choice.

If one accepts the concept that crystallite size determines mechanical properties, the data of Alkins[22] and Johnson,[23] Fig. 19, can be interpreted. In the initial stage of reduction, tensile strength rises by virtue of crystallite fragmentation. When the recrystallization deformation is reached, further crystallite refinement by fragmentation is halted. Deformation of the metal occurs merely by distortion of the crystallite shells until the temperature is raised by the heat released during deformation to the recrystallization temperature. When recrystallization commences, grain refinement by the hot working process proceeds and the tensile strength again rises.

If heavy reductions are used, metal temperatures may be high enough to achieve some recrystallization before recrystallization deformation is achieved; hence, the flat portion of the tensile strength–percent cold reduction curve is tilted so as to merge with the straight portions. Oxygen-free copper should be expected to deform with less generation of heat; hence, the greater degree of deformation would be required to attain the recrystallization temperatures as is shown in Fig. 19.

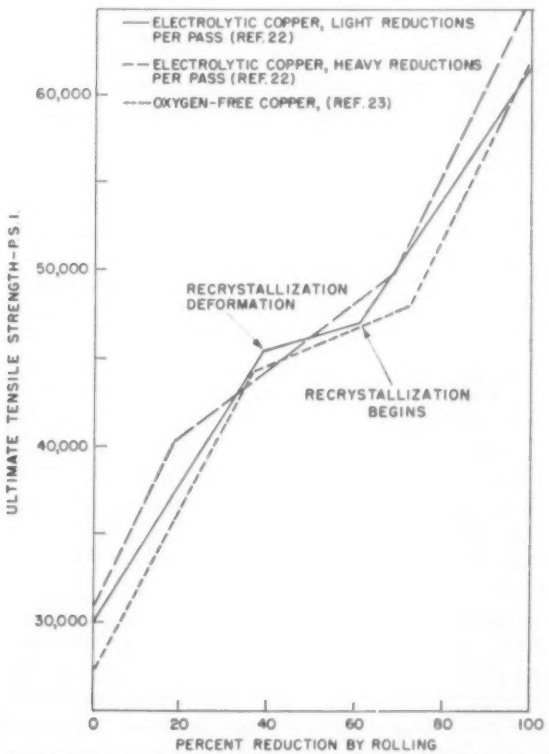

Fig. 19 The ultimate tensile strength of cold-rolled copper

This basic relationsh ip between properties and degree of deformation is of just as great fundamental significance today as it was over a generation ago. The discontinuities are attributed to structural changes which occur on deformation. At the first break, the point of recrystallization deformation is reached. At this point, there can be no further crystallite refinement by fragmentation. When recrystallization begins, further reduction in crystallite size is possible; hence, increased mechanical properties may be attained.

With regard to activation energy, it decreases with degree of deformation until the recrystallization deformation temperature is achieved, after which it is essentially constant, as indicated by the data collected from the literature, Table 6. The exact interpretation of this relationship in terms of structural change is not complete; further work in this direction may be of considerable value.

Table 6—Relationship Between Activation Energy, Degree of Deformation, and Recrystallization Deformation

Metal	*Deformation, %*	*Activation energy, cal/mole*	*Recrystallization deformation*	*Ref.*
Aluminum	5.0	64,500	30%	24
	10.0	59,600		24
	15.0	52,100		24
	30.0	51,240		25
Brass (70–30)	20.9	53,800	Greater than	26
	42.8	41,500	80%	
	60.4	32,300		
Copper	44.0	11,900	40%	27
	69.2	11,300		
	87.3	11,200		
	91.7	11,200		
	95.8	11,200		
	97.8	12,500		
Nickel	20.0	75,800	Greater than	28
	40.0	73,300	80%	
	60.0	69,500		

In closing, preliminary analysis of the data on recovery indicates that it follows the same temperature-deformation relationship as is followed by recrystallization. For small deformations, the value B in eq. 1 is dependent upon deformation up to a given deformation (8% in the case of electrolytic copper[29]) beyond which point it is constant in the same manner as the crystal boundary absorbed energy, V, is constant beyond the recrystallization deformation.

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Stress Concentrations in Steel Under Cyclic Load

Discussion by N. H. Polakowski

The writer proposes to comment on certain points raised in Professor Orowan's paper which, in the writer's opinion, are debatable. For convenience, the paragraphs below have the same numbers as the chapters in the paper to which reference is made.

(4) After discussing Fig. 6, the Author concludes that a steel with a high elastic limit and low plasticity will better stand repeated bending than a ductile one with low elastic properties. While this may be true in some circumstances, it may not necessarily be true in others. In this connection it is appropriate to point out that the case of the railway signal strand wires, quoted by the Author as confirmatory evidence, disproves rather than supports his thesis.

Brown[1] made it quite plain that in view of the discouraging experience made with the *normalized* medium-carbon wires, "... the British Standards Specification was revised and the revolutionary step was taken of imposing a maximum elongation in place of the previous minimum of much higher value, in order to ensure the supply of nothing but drawn wire for this purpose." The problem was thus not of hard steel versus ductile steel but of *cold-drawn versus heat-treated* material. Moreover, Brown ascribed the superiority of the drawn wire inter alia to its *low* elasticity compared with that of a heat-treated wire of equal strength.

This point is illustrated diagrammatically in Fig. 1 where Curves *1* and *2* represent, respectively, the "unsuitable" and "suitable" materials according to Prof. Orowan's argument. In actual fact wire 3 was found bad and was replaced by 4, showing a low elastic limit (or rather an absence of elasticity) which is a characteristic feature of drawn steel. When one recalls the classic case of the Mount Hope bridge suspension cables,[1–3] one can take as certain that material 5 in Fig. 1 would be inferior to 4 in the type of application under consideration, in spite of its higher strength and elasticity.

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Paper by Dr. E. Orowan was published in The Welding Journal, **31** (6), Research Suppl., 273-s to 282-s (1952).

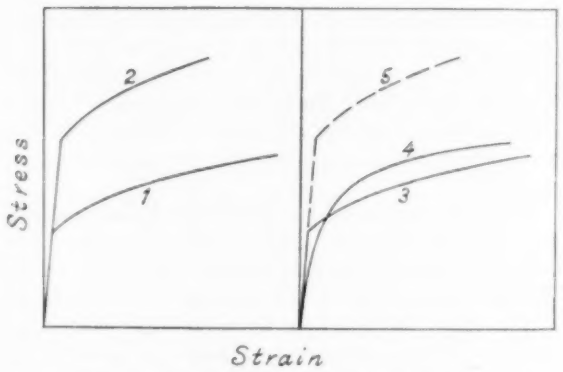

Fig. 1 Elastic and anelastic behavior of heat-treated[1–3, 5] and of cold drawn[4] steel, respectively (schematically). The high elasticity of the heat-treated material is a definite disadvantage in certain applications

The above remarks are not meant to say that the writer intends to deny the excellency of heat-treated high-tensile steel under different fatigue conditions than those above. But if it was the Author's intention to illustrate this fact, it is felt that the example chosen was irrelevant to his argument and therefore misleading.

(9) The assumption that the product of strain amplitude ϵ and the number of cycles to fracture N should be constant in the unsafe range does not agree with common experience.

Reversed bend tests on wire and sheet metal definitely show that doubling of the lip radius results in a disproportionate increase of the number of bends to fracture. Various formulas for calculating N for arbitrary lip radii were based on the relation $\epsilon^2 \times N = \text{const.}$[4, 5] Naturally, none was strictly correct since the behaviors of individual metals greatly depend upon metallurgical (structural) factors which cannot yet be expressed by elementary formulas. Nevertheless, these expressions took account of the fact that N increases faster than in proportion to the decrease of the cyclic strains.

The results of Tör, Ruzek and Stout[6, 7] do not seem to satisfy the $\epsilon N = \text{const.}$ relation in an acceptable manner either. The ϵN values are invariably greater with the small, 0.15% cycles than with those of 1%. The ratio ϵN (0.15%) : ϵN (1.0%) varies from 1.5 to over 6, with 2.5 as an average (Fig. 15[7]). The discrepancy is the largest for welding samples (over 500%) and it is just in and at the welds that structural inhomogeneities and stress concentrations are mostly apt to occur and where the assessment of their effects is of practical importance.

(12) The writer had some difficulties in interpreting Fig. 17 which is said to refer to the thin plastic surface layers of a bent bar or plate, presumably on the lines of Fig. 1 (*a*)

A stress-strain curve of the type in Fig. 17 is obtained when deformation is propagated by Lüders bands, as in plain tension tests. It may be inferred from the Summary, paragraph 5, that such deformation pattern was envisaged by the Author. If this is so, the location of point P midway on the yield "platform" has no physical meaning since there may be no single spot in the metal which received an effective deformation determined by the distance between O and the intersection of PP' with the strain axis. Such a position of P merely denotes that a part of the metal was "pulled through the yield" completely while the remainder did not yield at all. In low-carbon steel used for boiler plates the discontinuous yield may reach 2% plastic strain and it is hard to imagine how the outer surface can possibly receive such deformation if the material immediately underneath is supposed to be still in the elastic range. The writer wonders whether this reasoning is correct and would appreciate the Author's comments on this question.

The Author further suggests that "since nonuniformities of stress distribution are fairly effectively eliminated by plastic yielding before the strain-aging process, the point U may very easily be very high above P, etc." But he did not say that the second loading again involved a Bauschinger effect because the strains were here of an opposite sign to those during the preceding unloading operation. In this connection a reference to Fig. 2 may be of interest.

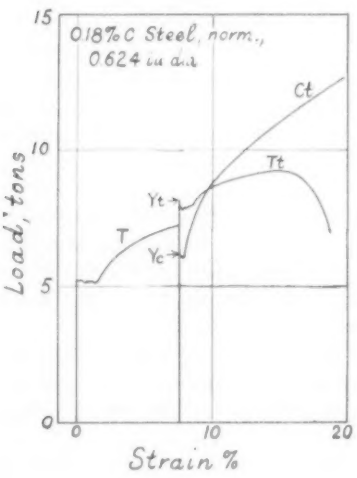

Fig. 2 Depression of the yield point caused by the Bauschinger effect. Even drastic aging (2 hr at 360° C) is incapable of raising the yield point in compression Y_c to the value reached at the end of the preceding tension

This test was carried out on a normalized round rod 0.624 in. diam, machined from a structural steel plate 3/4 in. thick. After about 8% extension (Curve T) the specimen was removed from the machine and aged for 2 hr at 360° C (712° F). A small cylinder was then cut off the strain-aged test rod and was compressed on the same machine producing Curve C_t. A tension test on the remainder of the rod yielded Curve T_t. It is seen that in spite of the drastic aging treatment, not only is the new compressive yield point Y_c considerably lower than that in tension Y_t, but that it is even below the value reached at the end of the first stretching T. This pattern of behavior is quite common in steels with over 0.1% C and, as will be seen from a comprehensive set of results which will be published in due course, it does not depend fundamentally of the initial overstrain.

In pressure vessels operating at nearly ambient temperatures, for example containers of compressed air or gas, the aging effect is quite small compared with that after 2 hr at 360° C used here. Under these conditions the effective yield points of the plastic spots may be very low indeed upon each consecutive reversal of straining direction, unless they are raised by work hardening. The latter, when combined with aging may perhaps result in a "shakedown" of plastic flow after a number of cycles, but it seems unlikely that strain aging should be on its own effective enough in this respect. At any rate, the justification for the assumption that U may rise very high above P between the end of one cycle and the beginning of the next one, is not obvious. Unless, of course, the Author's own experiments show the contrary.

Things may look differently at the elevated operating temperatures of steam boilers. But above 200–250° C the stress-strain curves of low-carbon steel do not show exaggerated yield points similar to that in Fig. 17. In consequence, neither the Author's arguments nor the discussion can apply to such conditions.

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Author's Reply

Dr. Polakowski attributes to me a statement I have not made when he writes: "...the Author concludes that a steel with a high elastic limit and low plasticity will better stand repeated bending than a ductile one with low elastic properties." In Fig. 6, which he interprets in this manner, I have merely proved that, at a stress concentration with given strain limit lines for cyclic loading, the final local stress amplitude reached after a large number of cycles is a higher fraction of the yield stress for a soft than for a hard material, and therefore the harder material will be the safer one, provided, of course, that the limiting safe stress amplitude is roughly proportional to the yield stress for the two materials compared.

I know that the railway signal wires according to British Standard Specification 163 (1936) were usually produced by normalizing whereas those according to B.S.S. 163 (1943) are cold drawn; but I cannot see at

(*Continued on page 256-s*)

Progress Report No. 8 on Welded Continuous Frames and Their Components

An Evaluation of Plastic Analysis as Applied to Structural Design

Design problems and trends in the application of plastic analysis as applied to structural design

by Bruce G. Johnston, C. H. Yang and Lynn S. Beedle

I. INTRODUCTION

THIS article presents a résumé of design problems and trends in the application of plastic analysis as applied to structural design. Many of the items discussed are being studied in research projects now in progress at Lehigh University and elsewhere. The results of these investigations may provide at least some of the answers needed to broaden the scope of application of plastic analysis in structural design.

This paper does not purport to be a survey of information on the plastic behavior of structures. For a demonstration of the validity of many of the statements made herein reference should be made to results of work carried on at the Fritz Engineering Laboratory of Lehigh University as described in Progress Reports 1 to 8, published or pending publication in THE WELDING JOURNAL and elsewhere.[1-8]

In 1945 the Structural Steel Committee of Welding Research Council suggested that work under its sponsorship at Lehigh University should at that time be directed toward the study of fully continuous welded frame construction. Tests of welded seat and top angle connections had been in progress but the opinion was expressed that the advantages of welding could best be exploited by directing further research toward the fully continuous welded beam or frame structure. A check on the validity of the assumptions that are usually made in continuous welded frame analysis as applied to conventional "elastic" design was desired. Also a complete study of the elastic and plastic behavior of continuous frames and their components was contemplated so that the current interest in the possibility of utilizing reserve plastic strength in the design of structures might be evaluated by actual tests.

The plastic or ductile behavior of steel as used in structural members and frames is important both to elastic and plastic design procedures. In the case of elastic design, the *inception* of plasticity is the essential design criterion (on the basis of stress calculations that neglect residual stresses and local stress concentrations). In "plastic" design the *maximum capacity* load of the structure is the principal design criterion. Deflection considerations *may* also be of importance in either elastic or plastic design.

At a meeting of the Lehigh Project Subcommittee of the Structural Steel Committee of Welding Research Council on Mar. 24, 1950, the following restatement of objectives emphasizing the importance of plastic behavior was approved:

1. To determine the behavior of steel beams, columns and continuous welded connections with emphasis on plastic behavior, and to develop theories to predict such behavior.

2. To determine how to proportion various types of welded continuous frames to develop the most balanced resistance in the plastic range so that the greatest possible collapse load will be reached.

3. To determine procedures of analysis that will enable one to calculate the collapse loads of welded continuous frames and to verify the analysis by suitable tests.

4. To determine procedures of analysis that will enable one to calculate the elastic and permanent deforma-

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To be presented at the National Spring Meeting, AWS, June 16-19, 1953, Houston, Tex.

This work has been carried out as a part of an investigation sponsored jointly by the Welding Research Council and the Department of the Navy with funds furnished by the following: American Institute of Steel Construction, American Iron and Steel Institute, Column Research Council (Advisory), Institute of Research, Lehigh University, Office of Naval Research (Contract No. 39303), Bureau of Ships and the Bureau of Yards and Docks.

tions in welded continuous frames in the range intermediate between elastic limit and collapse load.

5. To explore limitations in the application of plastic range design over and above deformation limitations, namely, fatigue, local buckling, lateral buckling, etc.

6. To develop practical design procedures for the utilization of reserve plastic strength in the design of continuous welded frames.

Methods for calculating the ultimate strength of continuous steel beams in the plastic range have long been available. In his *Strength of Materials*, Timoshenko[31] refers to the early work by N. C. Kist who in 1920 proposed a method of determining safe dimensions of steel structures utilizing ultimate load capacity in the plastic range. Referring to this method Timoshenko states "such a procedure appears logical in the case of steel structures submitted to the action of stationary loads, since in such cases a failure owing to the fatigue of metal is excluded and only failure due to the yielding of metals has to be considered." The early tests in Germany by Maier-Leibnitz[25] seem to have been directed toward removing some of the skepticism regarding such "new" ideas of continuous beam and frame design. Settlement of supports may cause changes in the stress distribution of such structures in the elastic range but Maier-Leibnitz showed that the ultimate capacity was not affected by such settlements. In so doing he corroborated the procedures previously developed by others for the calculation of maximum load capacity. However, little attempt to actually exploit the use of the ultimate load as a criterion of design appears to have been made at that time. The efforts of Van den Broek[32] in this country and J. F. Baker[13] and his associates in Great Britain to actually utilize the plastic reserve strength as a design criterion are well known and will not be reviewed. Recent progress in theory of plastic structural analysis has been summarized by Symonds and Neal.[30] A recent survey of design trends, by Winter,[33] discusses briefly many of the factors germain to plastic design.

Progress toward the utilization of the plastic reserve strength in steel structures as a design criterion can best be made by a full recognition and study of all of the various factors that affect the behavior of structures above the elastic limit. The study of such factors, as outlined under items 4 and 5 of the statement of objectives, has been one of the main purposes of the Lehigh investigation. For a brief survey of the Lehigh program reference may be made to a recent article by one of the authors.[15]

Before discussing the problems and limitations of plastic analysis as applied to design, it should be pointed out that there is no intrinsic logic in the argument that stress in a steel structure should not go beyond the elastic range. If such an argument is sound, then much of current design practice would have to be abandoned. Both in buildings and in bridges specifications allow the designer to use average stresses due to bending, shear and bearing that result in actual local yielding. Such cases occur in pins and rivets and at local points. This local yield results from stress concentrations that are neglected in the simple design formulas. Plastic action is depended upon to insure the safety of steel structures, and experience has shown that average or *nominal* maximum stresses form a satisfactory basis for design. Structural members experience yield while being straightened in the mill, fabricated in a shop or forced into position during erection. Actually it is during these three operations that ductility of steel beyond the yield point is called upon to the greatest degree. Having permitted such yielding in the mill, shop and field, there is no valid basis to prohibit it thereafter, provided such yield has no adverse effect upon the structure.

Plastic analysis, when applied to tier building design, may result in frames quite similar to those arrived at by the elastic analysis long customary. Those have usually assumed points of contraflexure in columns at half-story heights.[27] Wherever this assumption has been in error, there has been an actual moment (under the assumed loads) at one floor level, greater than calculated and acceptable only as the possibility of plastic action is acceptable.

Unfortunately, the procedure of basing design on approximations for real stress does not always give good results. The collapse of certain structures may be traced to the "trigger action" of neglected points of high stress concentration in material which, due to low temperature or other causes, may fracture in a brittle fashion. On the other hand, many structures are grossly "overdesigned" and wasteful of material. Better utilization of the maximum capacity strength of a structure is needed and research in this field will aid in realizing this aim.

In the earliest days of the art the "engineer" intuitively designed structures that, as a result of his experience and feeling for structural behavior, had the required strength and durability that was needed. Although theoretical analysis is now a part of all design procedure, experience is probably still one of the major factors in specification writing. Specifications should be the codification of good practice. As the engineer learned analytical methods of elastic stress analysis and coupled these with laboratory test results on the strength of materials and structural members, his attention was more and more drawn to the individual member rather than the whole structure. Now the trend in analysis and in the laboratory is back to a consideration of the complete structure rather than the individual structural component.

II. RESISTANCE TO BENDING MOMENT IN THE PLASTIC RANGE

In the simple plastic theory it is assumed that "hinge moments" successively develop at points of maximum bending moment in structural members. The approximate calculation of maximum load is then based on the static equilibrium of the structure incorporating such plastic hinge moments. In view of the obvious im-

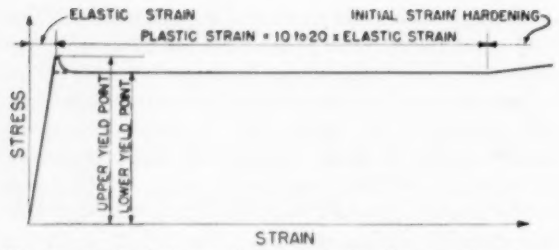


Fig. 1 Typical shape of stress-strain diagram for structural steel[1]

portance of plastic bending resistance, the following will outline and discuss in brief some of the factors that may affect the behavior during and subsequent to formation of hinge moments.

(a) The Moment-Curvature (M-ϕ) Relationship

Annealed structural steel has a nearly linear stress-strain diagram up to the yield level after which strains of 10 to 20 times the elastic yield strain occur with no increase in stress. There is currently much interest in theories and experiments to determine the conditions or experimental "law" for initial yielding of steel or other metals in a state of biaxial or triaxial stress. Such laws, however, are not a primary requisite in the prediction of the inelastic behavior of beams, columns and tension members. Such structural members are governed primarily by uniaxial stress. The ductile behavior of material in such a uniaxial stress system may be based on the properties determined by the simple tension or compression test.

If a structural steel beam is under pure bending moment, it will start to yield when the fibers furthest from the neutral axis reach the yield point (Fig. 1). After initial yield the relation between load and deflection of the beam will be nonlinear and will be determined primarily by the lower yield "level." The beam will resist an increasing bending moment approaching the "hinge moment" as yielding penetrates toward the neutral axis. This formation of the plastic hinge moment is shown in the M-ϕ curve of Fig. 2. Point 1 represents the elastic limit; at Point 2 the member is partially plastic; and at Point 3 the bending moment approaches the plastic hinge moment. The ratio of the hinge moment to the bending moment at initial yield is sometimes termed the "shape factor" of the beam. A wide flange (*WF*) structural section usually has a shape-factor of between 1.10 and 1.20. More compact sections have greater shape factors. For example, a rectangular beam has a shape factor of 1.50. Standard I-beam shapes with heavy web and small flanges will have greater shape factors than wide flange sections with thin webs.

The calculation of the moment vs. angle-change curve from a given stress-strain diagram for a wide flange section has been discussed in previous reports.[1, 4]

(b) Material Properties in the Inelastic Range

In the elastic range of behavior, up to loads allowed in conventional design, the deflections are very largely determined by the elastic modulus of the material, a constant that varies for steel within rather narrow limits. But in the plastic range, the primary factor determining the structural load-deflection relationship is the lower yield level of structural steel. Consider, for example, the plastic bending behavior of a wide-flange structural shape.

Figure 1, taken from the first Progress Report,[1] shows a typical conventionalized stress-strain diagram for structural steel up to the beginning of strain hardening; it includes the elastic strain, the upper yield point, the lower yield level and the plastic strain at lower yield stress level. This lower yield stress level is of fundamental importance to plastic analysis, and is a stress just sufficient to develop successive new zones of plastic slip in portions of a member adjacent to those which are still elastic or are passing through the upper yield point peak.*

* The upper yield point peak is neglected in ordinary plastic design procedures. This simplifies the stress-strain diagram to two straight lines (neglecting strain-hardening) and correspondingly simplifies the analysis (see dotted portion in Fig. 1).

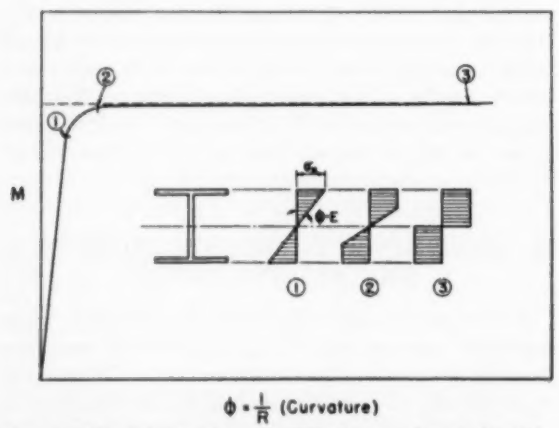


Fig. 2 M-ϕ relationship for WF shape. Stress distribution shown to correspond to points on curve[5]

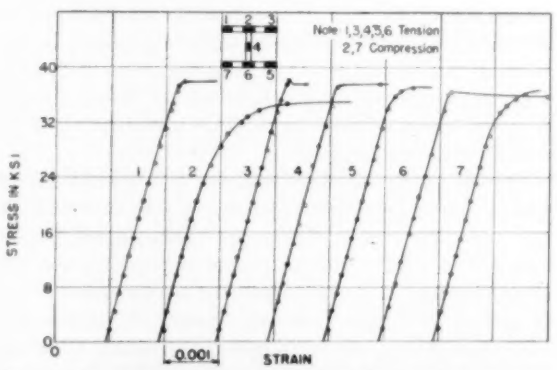
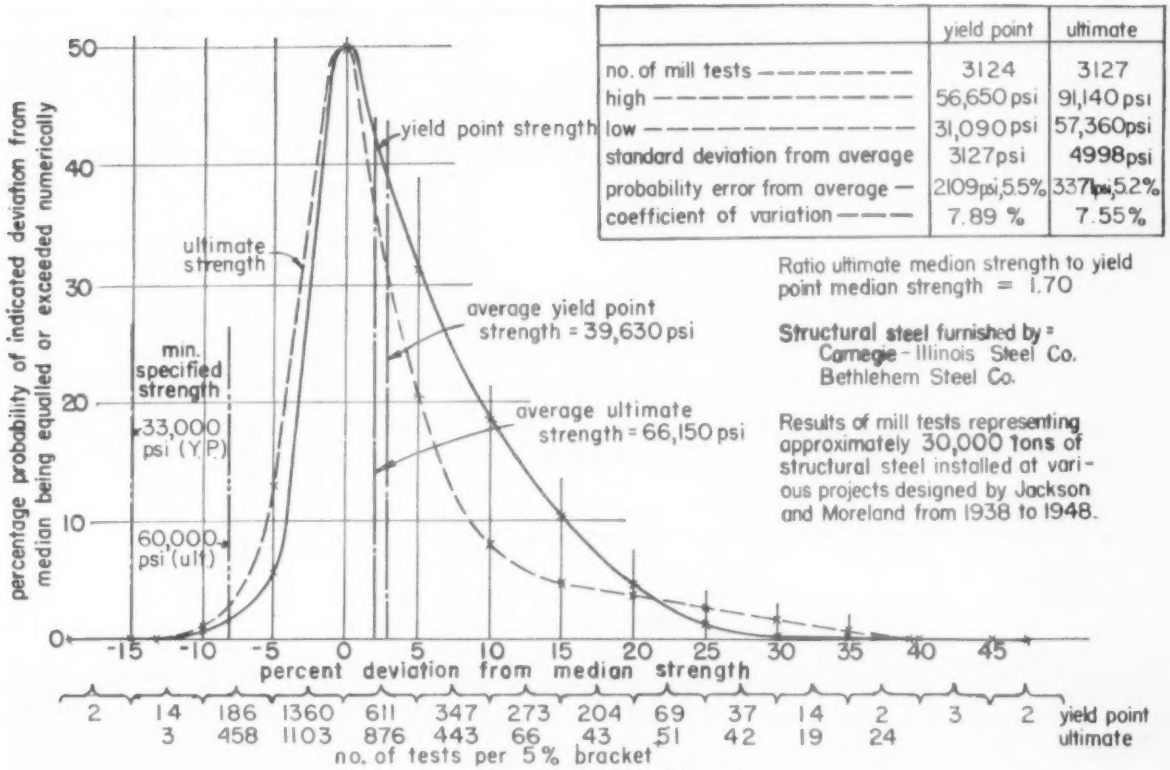


Fig. 3 Stress-strain curves for physical property coupons of 8WF40 as-delivered beam[1]


yield point strength
ultimate strength
average yield point strength = 39,630 psi
average ultimate strength = 66,150 psi
min. specified strength
33,000 psi (Y.P.)
60,000 psi (ult)
percentage probability of indicated deviation from median being equalled or exceeded numerically
percent deviation from median strength
no. of tests per 5% bracket
yield point
ultimate
Ratio ultimate median strength to yield point median strength = 1.70
Structural steel furnished by:
Carnegie-Illinois Steel Co.
Bethlehem Steel Co.
Results of mill tests representing approximately 30,000 tons of structural steel installed at various projects designed by Jackson and Moreland from 1938 to 1948.

	yield point	ultimate
no. of mill tests	3124	3127
high	56,650 psi	91,140 psi
low	31,090 psi	57,360 psi
standard deviation from average	3127 psi	4998 psi
probability error from average	2109 psi, 5.5%	3371 psi, 5.2%
coefficient of variation	7.89 %	7.55 %

Fig. 4 Results of mill tests[4]

In Fig. 3 it is seen that the yield level may be somewhat different in different parts of a given rolled shape. In Fig. 4, which is a plot of over 3000 mill test reports supplied by the courtesy of Jackson and Moreland Co., consulting engineers, it is seen that there may be a variation of 0 to +40%, more usually +10 to +30% above the specified minimum yield point, over various heats and various shapes rolled to a common specification calling for 33,000 psi minimum. The variations in Fig. 3 may be accounted for primarily by variations in rate of cooling; those in Fig. 4 by the same cause and also by differences in composition.

It is reasonable to suppose that mean strength levels may be taken as a basis for structural design with the factor of safety taking care of any variations. The yield level of structural steel to be used as a basis for plastic design must be converted from the reported mill test values to probable lower yield levels that are more significant. This conversion involves three main factors:

1. The difference between upper yield point and lower yield level.
2. The common practice of making mill tests from web material.
3. The accepted rates of strain used in mill tests.

The difference between the upper and lower yield point may be as much as 5% when tests are made according to common practice but will rarely be more than this. Likewise, the fact that most mill tests of wide-flange material are made from the web rather than the flange is of some interest since the flange is of greatest importance in relation to plastic bending strength. The yield point of the web material is frequently (though not always) higher than that of the flange, sometimes by as much as 5% or more, and the difference may largely be attributed to the more rapid rate of cooling of web material as compared with the thicker flange material. Thirdly, and most important, the lower yield level increases with increasing rate of strain. In order to get a correct evaluation of the "minimum" lower yield level it is necessary to make tests at an extremely slow rate of strain. In keeping pace with production, it would be impracticable for steel mills to make tests at such slow rates. A primary purpose of mill tests is for comparative quality control and the commonly accepted standard rate of strain is probably as good as any within practical limits. Some of the existing information on the effect of strain rate on the yield point of steel is as shown in Fig. 5, where the results of tests made by various investigators have been reduced to a common basis, namely, the ratio of yield level to that at a strain rate of 10^{-2} in./in. per sec. This strain rate corresponds very closely to the maximum permitted by ASTM Standard Specifications A6-50 covering the acceptance of structural steel. It is presumed that most steel mills will test at a strain rate very near the specified maximum, corresponding to a yield level approximately 10% more than that obtained for very slow static tests.

A combined reduction factor of 15% is suggested to take care of the three effects previously discussed.

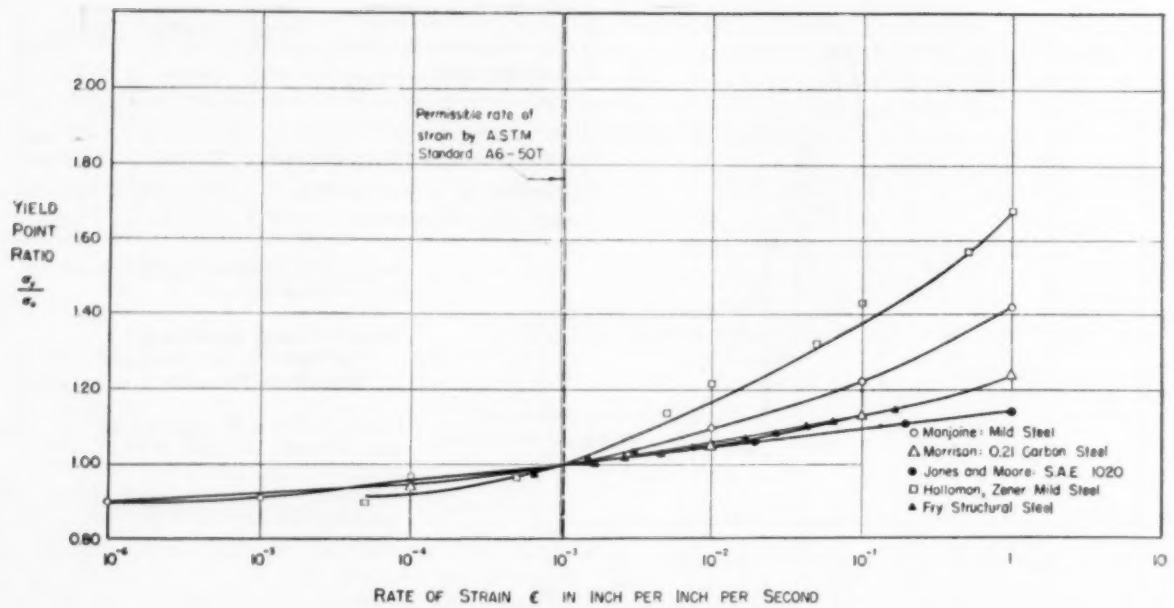


Fig. 5 Yield stress and strain rates for structural steel

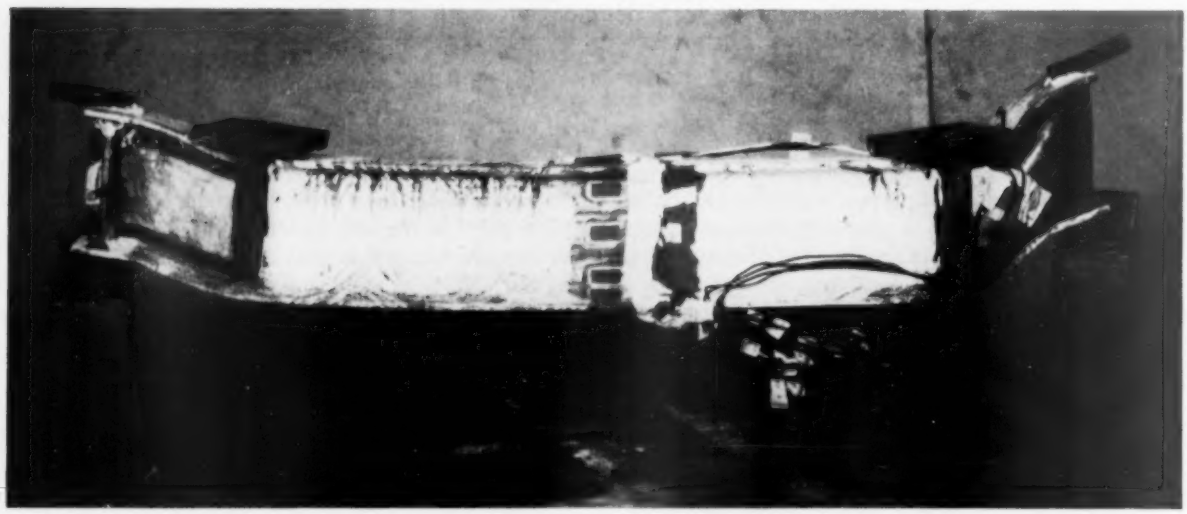


Fig. 6 American Standard I-beam (4-in.) at collapse

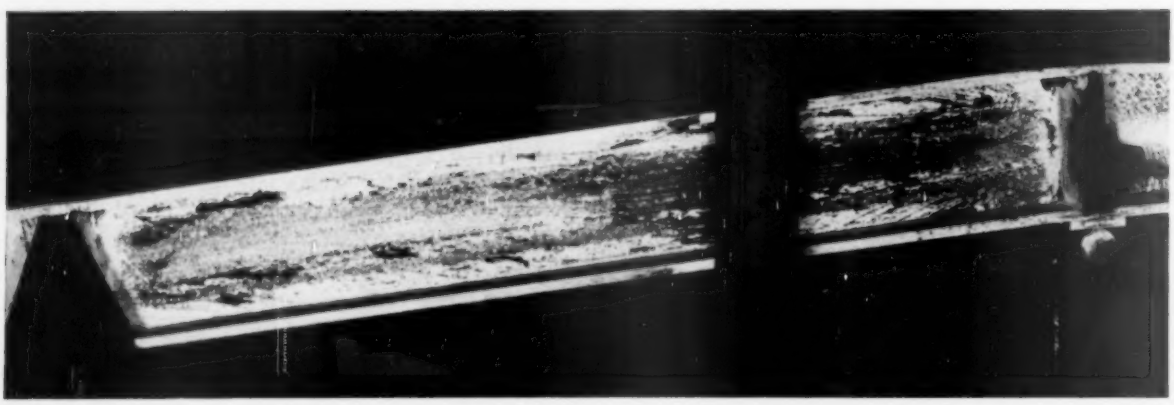


Fig. 7 Yield in 8WF40 beam web due to shear force

Applied to the mean value of mill tests (39,630 psi) indicated in Fig. 4, one is led to suggest the actual specification value of 33,000 psi as a lower level basis for plastic design computations—with the expectation that 10 to 15% lower values due to scatter must be tolerated, but that the factor of safety will take care of this variation.

(c) *Effect of Shear*

If high shear exists in the web of a structural beam over a considerable length, as in the case of a short beam centrally loaded, or a long beam with a concentrated load near the end, the beam may yield rather generally in shear thus causing larger deflections than might otherwise be expected. In some cases, the moment capacity is reduced. Two examples are shown in Figs. 6 and 7. The former is a 4 I 7.7 beam, simply supported, concentrated loads having been applied close to the ends. After general yield of the end panels under high shear, the web buckled, preventing the beam from developing maximum bending strength. (The beam exhibited a most satisfactory reserve of strength as regards shear failure.) Figure 7 shows that portion of an 8WF40 continuous beam between a support and a load point (a region of high shear). As contrasted with the 4-in. section, the "shear yield" load and the "moment yield" load are more nearly the same and the shape was able to finally develop the hinge moment, albeit with increased deflections.

In the case of shear combined with large moment, as at a support of a continuous beam, the effect may be somewhat different. The problem is a complicated one since the distribution of shear stress depends on the support details and the way the load is brought into the beam at the support. If the moment falls off rapidly away from the support, initial yielding due to shear and moment may be so localized that strain hardening will commence before any appreciable rotation develops. As an illustration, Fig. 8 shows a 14WF30 continuous beam at one of the supports. The region to the left is under high bending moment and low shear force; to the right, the shear force is high and the moment is decreasing rapidly away from the support. The web was able to carry the shear without yielding except in the region of high bending moment at the support. In such a case, the moment developed at the support may be considerably greater than the hinge moment predicted by simple plastic theory. In the case of very short beams, shear may inhibit the development of the full hinge moment. The problem of shear in its effect on hinge moment has been studied by Horne[22] for the case of the rectangular beam section, and similar considerations of the I-beam section are now in progress at Cam-

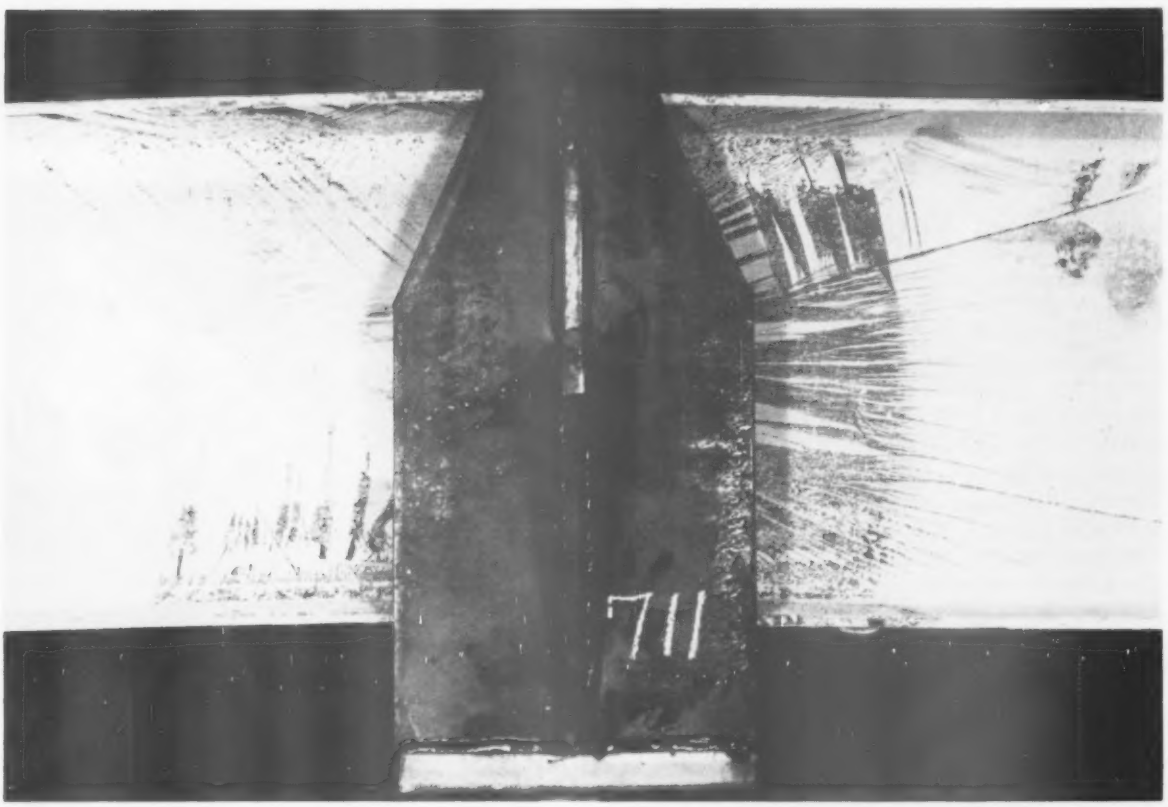


Fig. 8 Yield zones in 14WF30 beam at support

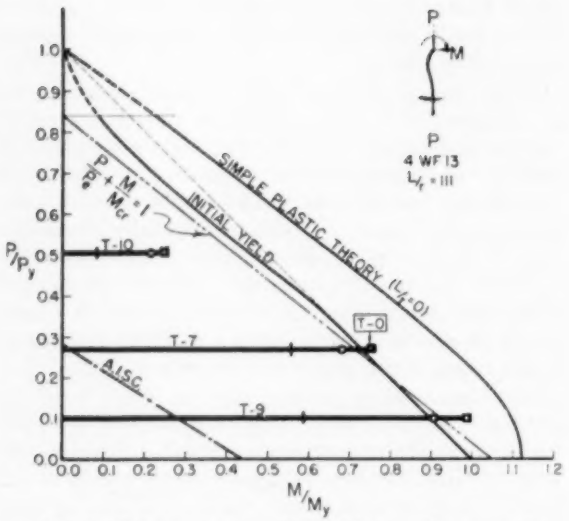


Fig. 9 Column test results and interaction curves[6]

bridge and at Lehigh University. The problem of shear as a primary design consideration will be discussed separately as Section IV of this report.

(d) *Effect of Axial Load*

The effects of axial load on moment capacity for various combinations of end moment and restraint are reported in Lehigh Progress Report No. 6.[6] In general, the effect of axial load is to reduce the moment capacity of a wide-flange structural shape. However, the effect is relatively small in certain cases of small axial load, small L/r ratio and compact cross section.

In a building frame, end moments are developed in columns and the combined behavior may be represented by an "interaction" curve in which plotted points represent simultaneously the relative proportion of axial load and bending moment at yield or maximum load. Figure 9, taken from Progress Report 6,[6] shows the interaction curve for a particular case wherein bending moment is applied at one end while the other is held fixed. The upper line indicates the theoretical ultimate strength of a very short column whereas the test results are for 4WF13 column with L/r of 111. It may be seen from the test results that initial yield and column collapse may occur at loads even less than those calculated for initial yield by the secant formula. The test results are not typical of those that may be expected from other combinations of applied load, moment and slenderness ratio but illustrate what may occur when residual stress accentuates lateral-torsional buckling tendencies.

In ordinary portal frame columns the ratio of axial to critical load is usually small so that any reduction in hinge moment may be ignored as is done in most studies of collapse strength. However, in the case of tier building structures, the resisting moment of the columns in the lower floors would be reduced by axial load and any evaluation of collapse strength in such a case should include consideration of this effect.

(e) *Effect of Local Buckling (Flange and Web)*

As reported in Progress Report No. 1,[1] wide-flange structural shapes have a flange thickness sufficient to insure against elastic buckling and will therefore develop the full yield strength of structural steel, except as modified by presence of residual stress. If the bending moments are uniformly distributed along a considerable length of beam as in a uniformly loaded beam with moment-free supports, or as in case of concentrated loads equidistant from the centerline, large deflections occur before local deformation results in marked plastic buckling of flanges. However, in tests of continuous beams, the more localized moments over the supports result in considerably greater local rotational deformations than for the simply supported beams. In such a case, for example, local *plastic* buckling did occur in the relatively thin flange of a 14WF30 simulated continuous beam.[5] The effect was to lower the maximum resisting moment at the support below the theoretical hinge moment and to produce a progressive lowering as rotation proceeded. This, indeed, is the danger of plastic local buckling: It prevents the section from sustaining the plastic hinge moment until hinges are formed elsewhere. Rotation capacity is the term applied to this property of structural components. Similarly, in the portal frame connection tests reported in Progress Report No. 4, Part 3[4] the following is quoted from the conclusions: "While some of the built-up knees have fair rotation capacities most of them collapse very rapidly after first local (plastic) buckling. This includes those

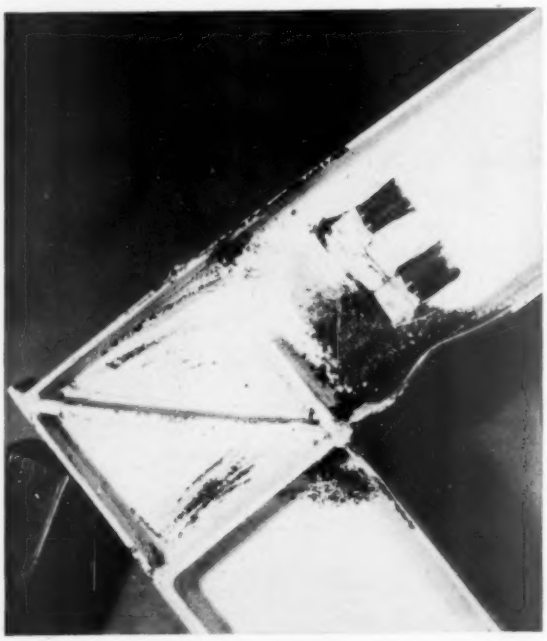


Fig. 10 Local buckling in flange of corner connection[4]

that are well-supported laterally. Rotation capacity is dependent on an ability of the knee to resist the tendency to local buckling. Thick flanges and effective lateral support are most helpful." Figure 10 from Progress Report No. 4, Part 1,[4] illustrates typical local buckling adjacent to a connection. Thick webs tend to support flanges against local buckling and improve the situation in this aspect of plastic design. Design rules for width-thickness ratios of flanges and webs will be needed in plastic design and these must be based on a study of plastic local buckling, a study that is currently under way.

(f) *Effect of Residual Stress*

In general, the effect of residual stress in a steel member is twofold: First, residual stress causes an initiation of yield at loads lower than expected according to usual stress analysis and thus, referring to Fig. 11, is a major factor in causing the uncertainty of actual deflections. Since residual stresses are erratic and, although usually present, have variable magnitudes anywhere up to the yield point of the material, the effect on the lower part of the load-deflection curve of a structure is obvious. Secondly, residual stresses may also lower the ultimate capacity by inducing either local or general buckling of a compression element or column. This is especially apt to occur if the elements are of intermediate slenderness between the elastic buckling (very slender) range and the very short and compact member that will develop full plastic yield strength even in the presence of residual stress.

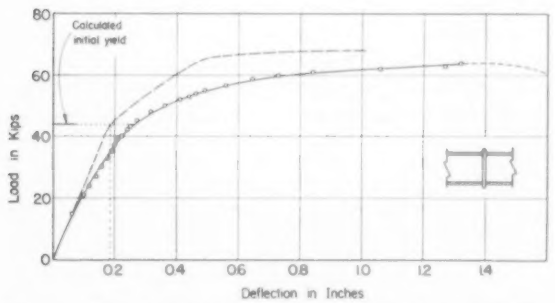


Fig. 11 Experimental and theoretical load vs. centerline deflection curves for 14WF30 beam[5]

The principal sources of residual stress are:

1. Uneven cooling of rolled structural sections immediately after rolling.
2. Cold straightening, punching, shearing or bending of sections.
3. Welding.

The effects of cooling and cold bending residual stress have been discussed at some length in Lehigh Progress Report 5.[5] A marked reduction in column strength of rolled WF sections occurs in the range of L/r between 40 and 100 as a result of residual stresses resulting from variable cooling rates subsequent to hot rolling. Figure 12, taken from that report, indicates a theoretical reduction that more recently has been confirmed by tests of actual columns.

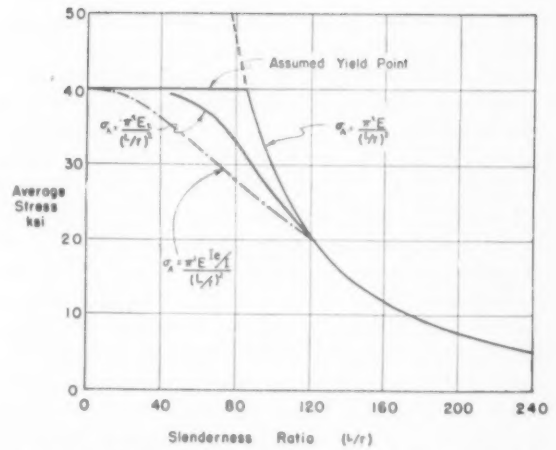


Fig. 12 Effect of residual stress on column strength[5]

It is expected that the distribution of residual stresses due to welding a built-up girder such as that shown in Fig. 13 would be similar to that found due to cooling after rolling. Compressive stresses would be found at the flange edges and tensile stresses at the flange center. Considerable variation from cross section to cross section is to be expected, however.

Figure 13

Effects of welding residual stresses have been noted in Progress Report 4[4] wherein residual stress is considered to have been the cause of local plastic buckling failure in the haunched knees along the inner compression flange. At this location the inner flange is a restrained compression member and it is known from the studies mentioned above that residual stress causes early yielding of the outer fibers of rolled flange sections, thus reducing the effective column section. Local buckling first occurs at the point of maximum stress. If this region is localized at the juncture between the haunch and rolled section and if adequate lateral support is provided at this point, the adverse effect of residual stress on the rotation capacity of the joint might be offset.

(g) *Effect of Lateral Buckling*

In plastic design, proportions of a structure must be such as to eliminate elastic buckling of any type, including elastic lateral buckling. Furthermore, plastic lateral buckling may lower the effective hinge moment in a continuous beam or frame member and may reduce the moment value during continued rotation in the plastic range, thus preventing the realization of the full plastic strength of a frame. End restraints and/or intermediate supports must be provided in plastic design

to eliminate the possibility of plastic lateral buckling prior to the development of full plastic strength.

Many tests of frames in the plastic range, often on small models, have involved solid rectangular bar sections bent about the weak axis.[12, 22] In such a case local and/or lateral buckling is not a problem. Tests by Baker and his associates also include small model frames using "broad-flange" sections but the extrapolation of these results to full-size structural members and frames is questionable. Work at Cambridge recently has included tests of nearly full-size continuous frames in which I-shaped members have been used. The work at Lehigh has put first emphasis on tests of nearly full-scale models of structures, simulating actual practice as closely as possible. Results of these tests have emphasized the need for adequate lateral support if plastic analysis is to be applied to design.

(*h*) *Unsymmetrical Cross Sections and Members of Variable Cross Section*

The solution of problems involving bending combined with torsion and/or unsymmetrical bending becomes extremely complex in the plastic range. It is probable that any initial consideration of plastic design primarily should make use of symmetrical sections combined with loading in either principal plane. Plate girders with variable length cover plates probably would not be designed according to plastic theory since the distribution of the material is based on distribution of moments and the elastic and plastic designs therefore would lead to approximately the same weight of structure. Another effect having to do with make up of member is the possible use of built up welded girders fabricated of rolled plates. These, because of greater depth, may not behave in the same manner as smaller rolled WF sections and the problems of local and lateral buckling may be more acute.

(*i*) *Effect of Encasement*

The encasement of steel members and connections in stone concrete for fireproofing may have a considerable effect on the plastic hinge moment and rotation capacity. These effects have been studied by Batho[14] but more research of this type is needed. Encasement may be of considerable benefit in reducing the tendencies toward local and lateral plastic buckling.

III. DEFLECTION DESIGN CRITERIA

One of the principal advantages of plastic analysis is the simplicity by which maximum load capacity may be determined as compared with procedures of indeterminate elastic frame analysis. If deflections must be calculated, some of this advantage in the plastic range is lost, although fairly simple procedures can be applied in some cases.[3, 8] A structure that deflects easily may produce undesirable motion due to vibration. Structural members supporting moving or dynamically applied loads also must have certain rigidity to permit proper functioning of moving equipment. There is a great need for more rational determination of proper limits to deflection in various structural applications—a need that will not be lessened in the advent of plastic design procedures.

In elastic design, deflections at allowable loads can be computed with a reasonable degree of certainty. In plastic design the same degree of certainty is not always possible. Figure 11, taken from a Lehigh Progress Report,[5] compares the theoretical and test results for a simply supported 14WF30 beam with cantilever sections extending beyond each support loaded so as to simulate a continuous beam between supports. Even in the so-called "elastic" range, as is clear from this curve, there may be a considerable departure from linearity of the load-deflection relation at working loads.

Considering the plastic range for such a case, the theoretical curve for load vs. deflection shows three straight-line segments. The first bend in the theoretical curve starts when the yield moment is reached at the supports and the second bend occurs when the yield moment is passed at the center of the beam span. Test results in the particular case illustrated fall far short of the theoretically computed values. The initial divergence from the theoretical values in the elastic range is primarily due to residual stress, and the lowered strength in the plastic range is due to local and lateral plastic buckling of beam flanges. This result is *not* necessarily typical but illustrates the divergence that *may* occur under conditions favoring plastic buckling.

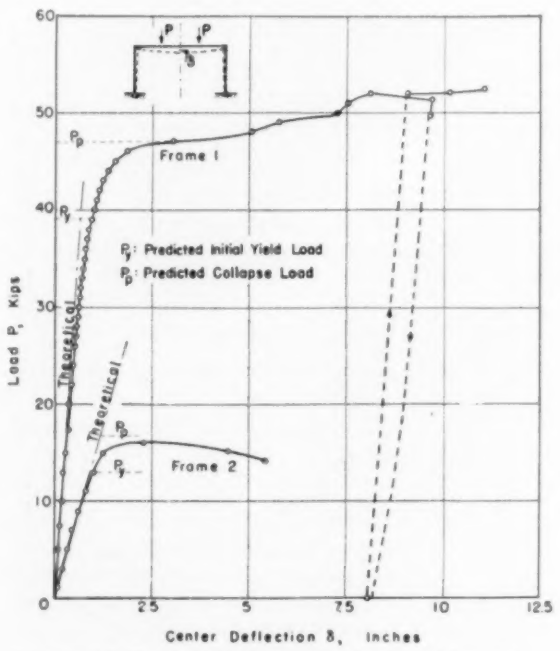


Fig. 14 Load-deflection curves for portal frames[7]

In the case of a beam with heavy flanges and corresponding good resistance to local plastic buckling, with the beam supported against plastic lateral buckling, the theoretical curve could be exceeded by the test curve, as has been observed in other tests.[5]

Load-deflection curves shown in Fig. 14 are for two of the portal frames tested under vertical load in another phase of the Lehigh investigations.[7] Deflections in each case deviated at low loads from those predicted by elastic theory. However, Frame 1, made up of 8WF40 members, developed the full strength predicted by simple plastic theory. Figure 15 shows a photograph of Frame 1 in its final deflected position. Frame 2, made up of 8B13 members, although of markedly greater susceptibility to local plastic buckling, developed 99% of its full strength (Fig. 14), although it did not sustain in the plastic range the strength that was developed.

If many duplicate structures were made to the same design and actually tested to failure, one should expect a considerable scatter due only to variation in yield point (Fig. 4). The factor of safety adopted in plastic design must recognize this uncertainty in maximum load. At allowable loads in plastic design, uncertainties as to deflection must also be tolerated, because of the effect of residual stress. The importance of deflection in plastic design is discussed in Progress Reports of the Lehigh series.[3, 8]

In a discussion of deflection it is of interest to refer to the AISC specification for buildings,[9] Section 17 of which reads, "the depth of beams and girders in floors shall, if practicable, be not less than $^1/_{24}$ of the span, and where subject to shocks or vibrations not less than $^1/_{20}$. If members of less depth are used, the unit stress in bending shall be decreased in the same ratio as the depth is decreased from that above recommended." The foregoing specification automatically limits deflection, although to a varying degree. In reference to restrained or continuous spans the next paragraph, Section 17b, reads, "Minimum depth ratios for restrained and continuous spans shall if practicable be such that the deflections at critical points will be not greater than those of simple spans of a minimum depth ratio recommended." A specification of this type should be one that is based on experience. Actually, the origin of these clauses is obscure and in some cases they may be unduly restrictive. It is quite probable that in many cases a structure designed by plastic procedures will actually deflect no more at working loads than an elastically designed structure meeting the foregoing specification.

In summary, the following may be said regarding deflections:

1. More realistic deflection design criteria are needed to supplant existing specifications and to define those conditions under which it is necessary to consider deflection in the application of plastic design.

2. In plastic design a somewhat greater degree of indefiniteness must be tolerated in actual deflection "scatter" at working loads as compared with elastic design.

IV. SHEAR AS A PRIMARY DESIGN CRITERION

Shear as a factor in altering the moment strength of beams has been discussed earlier but shear in itself may be the primary controlling factor in beam or frame design. It may be shown that the plastic design of symmetrically loaded, fixed-end WF beams with ratios of total span length to depth of as much as 8 to 1 may be controlled by shear. In the case of concentrated load near the support of a beam restrained at the ends, shear may be the primary design criterion in some cases if the load is at a distance less than four times the depth of the beam from the nearest support. Such load arrangements may occur in the use of offset columns in building frame construction.

Current "elastic" design specifications of AISC permit a lower factor of safety with respect to yield for shear failure in the web of beams as compared with moment failure due to direct stress in the flanges of longer beams. This was brought to the attention of one of the authors as a by-product of certain tests on seat angle connections.[24]

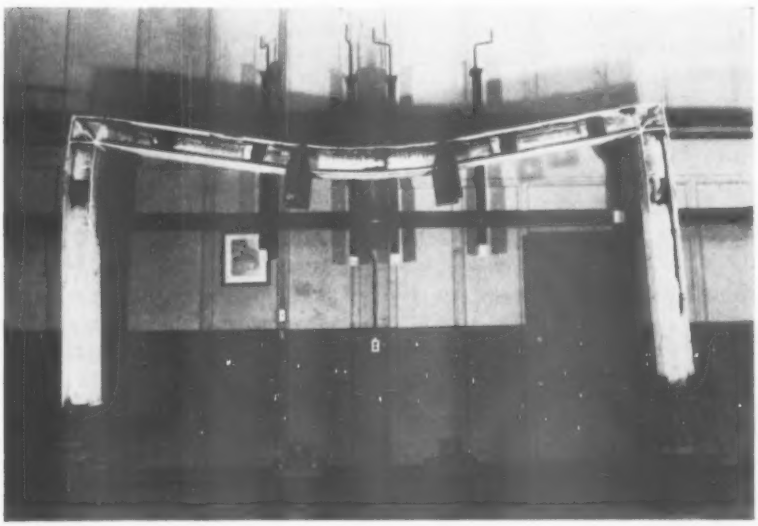


Fig. 15 Portal frame (8WF40) at end of test[7]

V. DESIGN FOR REPEATED LOADS

The importance of fatigue or repeated load as a factor in design of beams in the plastic range is apparent to a reader of the summary report on University of Illinois fatigue tests conducted by Prof. W. M. Wilson and his associates as reprinted in THE WELDING JOURNAL.[10] There

is, nevertheless, some grounds for encouragement on the part of the designer of any structure if 100,000 cycles of load or less are expected in which the load goes from a minimum stress of zero to a maximum value. In this range, beam sections fabricated with uniform cross sections and with continuous welds had fatigue strengths in which the initial stresses were above the yield point of the material. On the other hand, built-up beams with partial length cover plates (such as are used in elastic design procedures to distribute the material and utilize it at as high a stress as possible) had lower fatigue strengths than the beams with constant cross section. On this matter the article concludes, "any plain rolled beam without attachments or flange holes will have a greater fatigue strength than any cover plated beam or any built-up beam of the same or somewhat greater section modulus." Since the application of plastic design is best suited to the use of uniform beam and column sections, the relatively good fatigue strength of such members is of advantage to the plastic designer.

The uncertain fatigue life of connections such as are used in portal frames presents a limitation to both the "elastic" and "plastic" designer and more fatigue tests of such connections are greatly needed. Some indication of the problem is given by the fourth Progress Report of the Committee on Fatigue Testing.[18] In this report fillet welded tee joints were tested and the stresses for failure at 100,000 repetitions of load were far below the yield point of the material. Simple and economical portal frame connections of the square knee type almost always include a connection of this type at a region of maximum moment. Fatigue failure in such a connection is likely within a few thousand cycles of load but there is a lack of sufficient information to form definite conclusions and until further test work is carried out it seems essential that the application of plastic analysis to structural design be confined, in portal frames, to those cases where only a very few repetitions of maximum loads are to be expected during the life of the structure. An intermediate condition might arise wherein a design for repeated loads at reasonable elastic stress levels might be made with only occasional overloads anticipated due to abnormal wind or snow load conditions. Plastic design then might be used for the consideration of the heavy overloads to be expected only once or twice during the life of the structure.

VI. SHAKEDOWN

The question of "shakedown" has been explored in detail in research at Brown University. The subject also has been reviewed elsewhere.[30] Shakedown is a term applied to a critical load, P_s, intermediate between an upper limit of P_p (maximum plastic load) and a lower limit of P_y (load at initiation of yield), and above which under repeated applications of a certain sequence of load an increment of plastic deformation in the same sense may occur during each cycle of loading, thus leading to ultimate excessive deflections and possible fracture. In some cases the critical shakedown load is equal to the full load P_p and in other cases it may be as low as the elastic limit load P_y. Obviously, under repeated load cycles, shakedown may be an important consideration in plastic design.

VII. STRAIN AGING

Detailed coverage of the problem of strain aging, like that of shakedown, is outside the scope of this paper but it is mentioned as of possible importance to plastic design. In particular, it may increase the chance of brittle fracture, a matter to be discussed as the next item. In a general review, Epstein[20] states: "Aging is a change that occurs in the properties of iron or steel at atmospheric temperature or at a moderately elevated temperature after rapid cooling or after cold working. . . 'strain aging' is the term applied to the changes that take place when the final operation consists of cold working. Aging may result in an increase in hardness and strength; a loss in ductility and impact resistance..." Permission of rather general plastic flow as a design basis in a steel subject to strain-aging would enhance the possibility of brittle fracture. The phenomenon of strain aging has been noted in tests of ordinary wide flange beams in the plastic range.[1]

VIII. BRITTLE FRACTURE

The question of brittle fracture is a most important one since structural engineers have been plagued in recent years with failures of bridges, pressure vessels and ships wherein the steel has fractured with none of the ductility associated with the usual laboratory tensile test in which considerable elongation, both uniform and local, takes place prior to fracture. The type of fracture occurring in these disasters has more closely resembled that of glass than that normally to be expected in a steel structure. One of the most recent failures of this type is that of the Duplessis Bridge in Canada.[26] In the early correspondence that led to the conception of the present article, F. H. Dill, Welding Engineer of the American Bridge Co., wrote as follows:

"The rise of the idea that the plastic strength of steel may be utilized to gain greater economy in the design of steel structures is alarming when it is set against the long known and recently reproved fact that structural steel under many common circumstances has *no* plastic action. It is alarming even when it is intended to use the reserve plastic strength only to increase the allowable elastic working stresses. Such an increase of allowable working stress will inevitably create more regions of yield point stress and even extend them into primary members. This creates an unacceptable condition because, when there is no plastic action, these stresses can cause fractures and failure of the structure.

"If it could be proved that there is *always* a predictable amount of plastic action or reserve plastic strength in structural steel, it would be acceptable to count it in

the design of structures. Until this condition is proved, however, the possibility that there may be *no* plastic action must be recognized and the designs of structures planned accordingly."

Whether or not one agrees with Mr. Dill, his viewpoint is held by a number of structural engineers. Some will argue with good supporting evidence that it is impossible even in "elastic" design to guard completely against the possibility of brittle fracture. Such fractures seem to be caused by an unfortunate coincidence of a number of adverse factors that in a given structure may occur in combination so rarely that the possibility of such brittle failure must be accepted as a calculated risk. Others may argue that a proper combination of good material, skilled workmanship and adequate structural design of details can be achieved by specified good practice so as to insure against any possibility of brittle fracture within the range of allowable loads including the possibility of some plastic flow. This is certainly a desirable goal but it is a difficult one to achieve as is attested by the many failures on record. Certainly it seems true that brittle fractures are caused by a combination of adverse circumstances that may include several of the following:

1. Local stress concentrations.
2. Poor welding.
3. Notch sensitive steel.
4. Shock loading.
5. Low temperature.
6. Strain aging.
7. State of stress combination in which all three principal stresses are tensile.

The problem as applied to bridges has been discussed in general terms by Bijlaard[16] and literally hundreds of references could be cited as examples of individual investigations that have resulted indirectly from failures of welded ships and pressure vessels during and subsequent to the last war. These failures, in spite of improvised measures to reduce them, still occur occasionally and several ships were lost during the past two winters. However, as has been pointed out, this limitation applies both to elastic and plastic design. Thus, any steps taken to protect "elastically designed" structures from brittle fracture should also benefit a structure designed according to the concepts of plastic analysis.

IX. THE DESIGN OF DETAILS

It is generally recognized that the most important problems in structural design concern design of details such as connections rather than the design of the main members. Main members are rather thoroughly covered by specifications, but in the design of details the engineer is called upon to exercise the greatest amount of individual judgment and the wisdom that comes only through experience. Here, in the details, the engineer departs the farthest from elastic stress analysis procedures and either by use of approximations based on his own experience and judgment or by use of existing

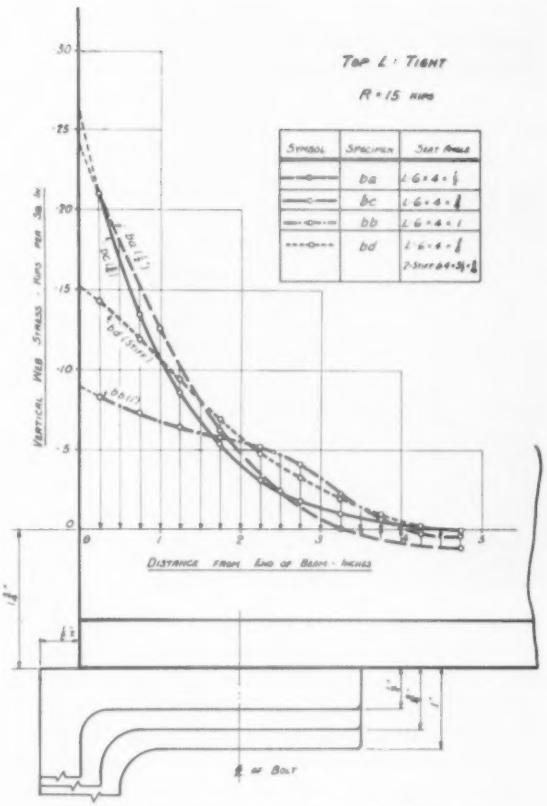


Fig. 16 Vertical web stress in 12WF50 beam[24]

specifications (if these cover the case in hand) *plastic design in a restricted sense has always been common practice.* A typical example is that of the design for the local compressive stress in a beam web above a support or under a concentration of load. An average stress here of 24 kips per square inch is allowed by the American Institute of Steel Construction Specifications.[9] When a beam is supported on a seat angle there is a concentration of stress at the very tip end of the beam so that the yield point is reached at reaction loads which may be lower than the allowable load as calculated by the empirical formulas currently used in design. This fact has been corroborated by unpublished test results based on work done at Lehigh University in 1941.[24] Figure 16 shows the measured stress distribution for these tests of centrally loaded short 12WF50 beams, indicating a reaction of about 22 kips at initial yield. (With loose top angles the reaction at initial yield would be much lower.) The allowable end reaction of the beam would have been 45.6 kips. (The AISC table of load values for unstiffened seats seems overly conservative as it would automatically limit the design (reaction load) to 35 kips in this case.) Nevertheless, in the test, the only evidence of failure was a gradual spread of the yielded zone from the end of the beam toward the toe of the seat angle. This spread was appreciable at 40 kips but the beam continued to take loads up to 80 kips without serious signs of distress. Figure 17 shows the

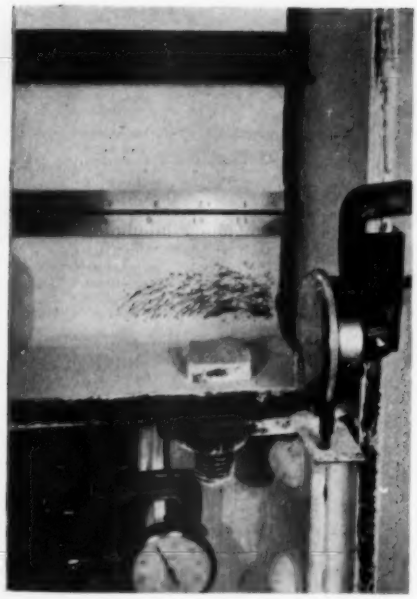


Fig. 17 Yield zone at 70-kip load[21]

spread of yield at the 70 kip load and Fig. 18 presents curves of reaction vs. deflection at the connection for the various tests that were reported. Above 80 kips the compression yield in the web of the beams had spread to such an extent that barely perceptible local buckling developed as indicated by dial gages but not to an extent easily noted by eye. At a maximum load of 90 kips lateral buckling amounted to approximately one-tenth of an inch. At this load the beams had failed rather generally in shear and the tests were stopped. Within the range of the test program the type of seat had no marked effect on ultimate capacity and AISC Specification practices for beam web crippling and unstiffened seat design were shown to be overly conservative.

Many other examples could be given similar to that of the seat angle connection. In general, where local concentrations of stress exist and where there is a surrounding region of low-stressed material or adjacent parts in a built-up member, or where proportions are "compact" so as to prevent local buckling, loads much greater than those causing initial yield may be withstood without serious deformation of the structure as a whole. Furthermore, in cases where the stress is predominantly compressive, there is reduced danger of failure by fatigue or by brittle fracture.

Other similar cases include the design of rivets and pins in shear, bearing and (in the case of pins) direct stress due to bending. The high allowable stress in pins for direct stress due to bending (30,000 psi by AISC Specifications) may be justified by the high plastic shape factor for the circular section which is 1.70. Considering plastic behavior there is thus a factor of safety of $1.70 \times {}^{33}/_{30} = 1.87$ which is greater than the value of 1.65 as sanctioned by AISC for tension members. In the case of the riveted connection, the stresses allowed in bearing and shear would permit local yielding in an individual rivet and adjacent plate, were it not for friction between elements, and, furthermore, in the case of a large connection with many rivets, the end rivets are known to be stressed at much higher levels than those in the interior. The outer rivets must yield and deform first, thus causing a redistribution of load to the various rivets that is entirely analogous to the successive formation of moment hinges assumed in the plastic analysis of the continuous frame.

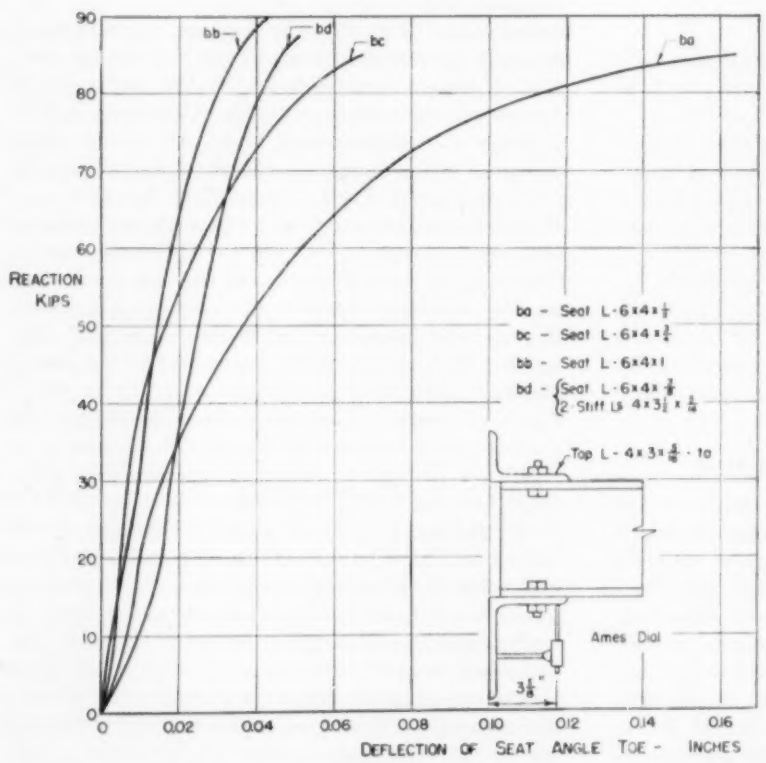


Figure 18

Since the design of structural details is already based on a restricted application of plastic design theory, it is obvious that in the advent of a broader application of plastic design no great change is to be expected in this very important aspect of structural design. It may be necessary for the engineer to give even more careful consideration to structural details if an over-all balanced plastic strength is to be realized. This has been particularly evidenced by the tests of various knees for portal frames as reported in Progress Report 4.[4]

X. ECONOMY IN PLASTIC DESIGN

Is there any real economy in plastic design procedures assuming that all of the design criteria are adequately satisfied?

In the use of rolled structural shapes, there is little economy in plastic design if the structure is determinate since, in this case, both procedures give essentially the same answer. Any difference is due to the shape factor alone. The same is true under certain special cases of continuous beams, as for example, the fixed-end beam with a concentrated load at the center. Another instance is that of a three-span continuous beam with the span lengths adjusted in such a way that maximum moments at the center and at the supports are approximately equal.

Economy is to be achieved through the use of plastic reserve strength whenever (for a given load in the elastic range) there is a *difference* in the magnitude of bending moments under the loads and at the supports of indeterminate structures. Since yielding occurs at the point of maximum moment, plastic design makes use of the moment difference mentioned, a reserve that is disregarded in elastic design.

As a simple example of conditions wherein plastic design does show advantages of economy, consider Fig. 19 which is taken from the review of the Lehigh research program as presented by one of the authors at the 1952 National Engineering Conference of the American Institute of Steel Construction.[15]

"Assume a working load of 21 kips. If the ends are simply supported, an 18WF50 shape is required. The elastic limit is the implied 'Full Load,' or working load multiplied by the factor of safety.

"If the ends are 'fixed' against rotation, according to conventional elastic design procedure a 16WF36 shape is indicated. The load at initial yielding is the same as in Case I, but obviously the reserve in strength is considerably greater.

"Finally, if we use one of the available plastic design procedures, the weight can be reduced an additional 20% (14WF30). (The example shown makes use of one of the most conservative plastic methods yet suggested.) The things to note about the results are:

"(*a*) The full load (working load times factor of safety) for Case III has the same rational basis as Case I—the load at which deflections commence to increase at an uncontrolled rate.

"(*b*) At working loads the structure is still in the so-called 'elastic range.'

"(*c*) The deflection at working load for the plastic design is less than that of the simply supported beam and only slightly greater than that of the simple beam at full load. Also note that it is well within the specification limit."

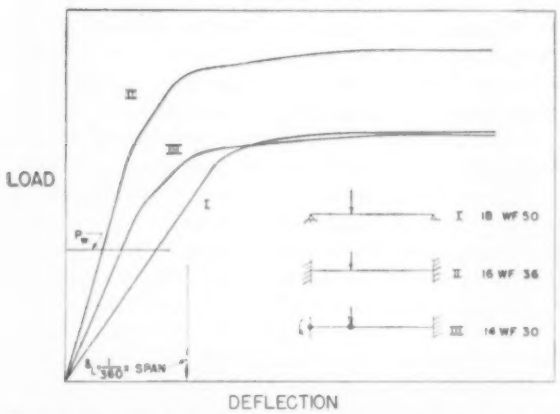


Fig. 19 Approximate load-deflection curves for three beam designs[15]

In the next section mention is made of an actual building in which substantial savings were made by use of the plastic method. There is also on record[28] a comparative design by J. F. Baker and collaborators involving a building that covered an area 470 by 208 ft. When designed elastically, the total weight of steel was 181 tons; plastic design called for but 118 tons—a savings of more than 34% of main material!

In the design of structures for high wind loads and maximum snow loads it is to be expected that such load magnitudes will occur only a few times in the life of a structure. In such cases plastic analysis would seem to have a very definite application especially in design of tier buildings, warehouses and industrial plants where small permanent deflections could readily be tolerated. A possible exception to the permissibility of such deflections would be in case of industrial mill buildings that have crane runways in which misalignment of runways would create malfunctioning of cranes. Allowable stresses are increased in the elastic design consideration of unusual load combinations that include wind. Plastic design procedures would need the same consideration to effect great saving over the procedures now used. Nevertheless, the utilization of plastic design for these unusual load combinations would be a more realistic approach than the present procedure of simply increasing the allowable stresses. The result would give a structure of balanced strength and there would be the possibility of savings of material.

XI. TRENDS IN STRUCTURAL DESIGN

As an intermediate step in the application of plastic design, as applied to tier buildings, the use of "semirigid connections" should be mentioned. This has been permitted in principle since 1946 by the AISC "Specifications for the Design, Fabrication and Erection of Structural Steel for Buildings."[19] Semirigid connections have been used in the design and construction of building frames in this country and a tentative specification and design procedure is available.[21] As in the case of the current trend in plastic design, the work of Baker and his associates in England was the forerunner of the current use of semirigid design in structural steel framing in this country.[29]

Referring now to plastic design, as permitted in Eng-

land, British Standard Specification BSS 449 allows the designer to use the "load factor" design method so long as due account is taken of deformations and accurate methods of analysis are used. Section 29c states, in part:

". . . For the purpose of such design accurate methods of structural analysis shall be employed leading to a load factor of 2, based on the calculated or otherwise ascertained failure load of the structure or any of its parts, and due regard shall be paid to the accompanying deformations under working loads, so that deflections and other movements are not in excess of the limits implied in this British Standard."

The application to actual portal frame design is given in some detail in the recent publication of the British Constructional Steelwork Assn.[17] Apparently, one of the first uses of this specification was in the construction of the gabled continuous welded frames for the new laboratory of the British Welding Research Assn. at Abington.[11] According to the cited reference, the design of this frame showed a reduction of approximately 45% in comparison with "truss and cantilever column" design and 17% in comparison with elastic design of a similar welded continuous frame. One reason cited by the authors for the small difference is the fact that greater load factors are required in the specification for plastic design as compared with those covering elastic design. On the other hand, the authors also point out that no lighter frame could have been used because of prohibitive deflections.

In this country, as previously mentioned, the AISC Specification[9] permits an increase of 20% for stress at the supports of fully continuous beams and girders as compared to other locations "provided that the section modulus used over supports shall not be less than that required for the maximum positive moments in the same beam or girder, and provided that the compression flange shall be regarded as unsupported from the support to the point of contraflexure." Similarly the specification goes on to permit a bending stress in columns of 24,000 psi "when this stress is induced by the gravity loading of fully or partially restrained beams framing into the columns."

It is thus seen that two different approaches to the utilization of plastic reserve strength are currently in process of development. The one, as exemplified by the British Specification, would determine actual "ultimate" or "full" or "limit" loads and divide these by a "load factor," keeping in mind necessary restrictions as to deflection of the structure, possibility of fatigue failure, etc. The other, already partially in use in the AISC Specification, would determine variable permissive stresses due to bending depending on the degree of restraint and distribution of load.

At the moment, one of the most important uses of methods for analyzing the plastic ultimate strength of steel frames lies in the realm of military applications. Such applications gave impetus to some of the developments of plastic theory in England under the direction of Professor Baker and his group at Cambridge.[12] Much work is under way at present on the prediction of strength and behavior during failure of buildings subjected to blast and shock of atomic bomb burst and recent studies indicate the relative superiority of continuous welded frame construction for certain simple types of industrial building frames.[23]

In summary, plastic design methods seem applicable to certain types of construction provided specifications are made available that will give proper attention to the various limitations discussed herein. The following are enumerated as a partial list of examples:

1. *Tier building frames with fully continuous welded construction.* There will be some possible exceptions if repeated loads are expected. Plastic analysis should be applicable for design of maximum combinations of gravity load. In the case of lateral wind loads, as has been pointed out, results similar to those obtained by limit design concepts have already been in use for many years.

2. *The design of industrial building frames.* Plastic analysis procedures might produce a better distribution of material for effective over-all strength against the occasional high wind and/or snow loads to be considered. Special attention would be given to permissive deflection in the case of industrial building frames carrying crane runways which require accurate alignment to insure correct functioning of cranes.

3. *Structures intended to absorb dynamic loads.* Any structure actually designed to absorb such loads as those resulting from bomb burst or possible collision should be designed by plastic analysis procedures. Only thus can the energy existing during impact be absorbed effectively.

XII. SUMMARY

This paper has discussed design problems inherent in plastic analysis as applied to design. These have included the problems of limiting deflection; reduced plastic moment as affected by shear, axial load, local buckling, residual stress, lateral buckling, etc.; the problem of design of details; shear as a primary design criterion; fatigue; shakedown; and the possibility of brittle fracture. Many of these problems also exist in conventional elastic design. Possible applications for plastic design have been outlined in brief. Some phases of the projects in progress or completed at Lehigh University have been reviewed where pertinent.

A careful study of the problems herein enumerated should stimulate application to those areas of structural engineering wherein plastic procedures do have a place. The goal in structural design is to provide a safe and enduring structure that incorporates maximum possible economy. If plastic analysis can be applied to design to realize these goals, it will be so applied, for the laws of evolution work as surely in the history of man-made structures as they do in the field of biology. Progress in the application of new concepts is slow because the final test is in the actual structure and not in the theory that guides the designer. Theories that do not

give full recognition and delineation to limitations in application to practice will deter rather than aid the progress of structural engineering. Hardy Cross in his recent book[19] states:

"Many articles purporting to be new appear in the field of analysis. Sometimes such articles are useful; often they are harmful. In the field of civil engineering the designers and builders are the men on the firing line."

Eventually what is really needed is a reliable specification that will guide the designer using plasticity as a basis. In the development of such a specification, new criteria for width-thickness ratios of plate elements and column and beam proportions must be established so as to permit application of the principles of plastic analysis in structural design. The proper writing of a specification will require a complete rethinking along plastic rather than elastic lines.

Actually the idea of designing a structure on the basis of ultimate load capacity rather than on allowable stress is simply a return to the realistic point of view that had to be adopted in a very crude way by our ancestors when they did not possess the knowledge of mathematics and statics necessary to the calculation of stresses. The development of mathematical procedures for stress analysis has not been without its drawbacks since it has tended to overemphasize the importance of stress rather than strength as a guide in engineering design. Now, then, the rules of plastic analysis are becoming available to permit a return on a rational basis to over-all strength as the most valid basis for structural acceptibility.

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Progress Report No. 9
Welded Continuous Frames and Their Components

Plastic Strength and Deflections of Continuous Beams

Possible savings by using plastic design as distinguished from conventional elastic design with a suggestion for a specific design criteria

by K. E. Knudsen, C. H. Yang, Bruce G. Johnston and Lynn S. Beedle with an appendix prepared by Walter H. Weiskopf

Abstract

While conventional structural design according to the theory of elasticity gives assurance against excessive deflections, the application of design methods based on the ultimate carrying capacity of a structure necessitates special consideration of critical deflections. The simplicity of the so-called plastic design methods may be overshadowed by time-consuming deflection computations unless reliable approximate approaches can be applied.

This paper demonstrates several methods for computing deflections due to bending of mild steel beams of uniform cross section. The effect of various simplifying assumptions which greatly reduce the numerical work involved is shown together with comparison with experimental results. The influence on the deflections of various degrees of end restraint and load distribution is computed.

The paper demonstrates for several loading conditions on continuous beams the possible savings by using plastic design as against conventional elastic design and suggests a specific design criteria applicable to the examples given.

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INTRODUCTION

THE prediction of deflections of mild steel beams strained beyond the elastic limit is an important part of design methods based on the ultimate carrying capacity. This concept of structural behavior emphasizes collapse (or excessive deformation) rather than a maximum unit stress as the limiting criterion on structural usefulness.

Structural design methods based on the theory of elasticity, except in problems of elastic stability, define as the limiting useful load the load causing initial yield at the most highly stressed location in the structure. The working load is taken as a certain safe fraction of this yield load, and will leave the entire structure well within the so-called elastic range. The deflections in many cases constitute no major design consideration and are readily estimated for those cases in which certain limits are imposed on their magnitude.

For statically determinate structures and in problems of stability the two concepts of structural carrying capacity yield basically the same solution. In the analysis of redundant structures, however, the differences are great.

Initial yield at some location in a redundant structure does not render the structure incapable of carrying additional load. The maximum elastic deflection of a redundant structure is generally less than that produced by the same loads on a structure having identical members but lacking in continuity at the joints. Although the deflections will increase at a faster rate above the yield load than in the elastic range, danger of imminent collapse is obviated by the ability of mild steel to relieve the most highly strained portions of the structure. The strain-hardening characteristic of structural steel further increases the margin between initial yield and ultimate collapse. A similar influence is observed due to catenary stresses set up in beams which are not allowed to move horizontally at supports. Neglecting strain hardening and catenary effects, collapse occurs when a sufficient number of cross sections have yielded, thus causing the entire structure or a part of it to act as a mechanism under any further increase of load.

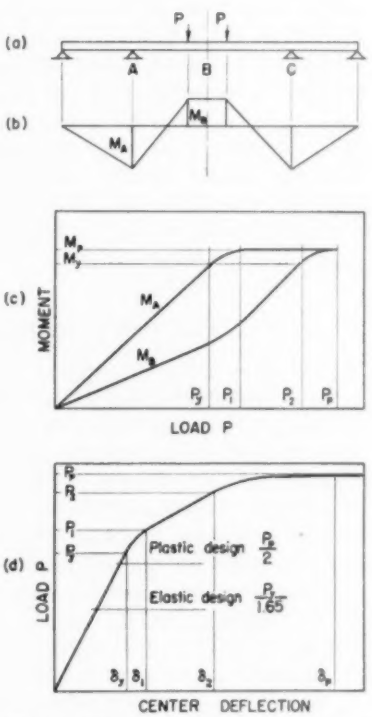


Fig. 1 Moments and deflections of continuous beams

As an illustration, consider a beam over three spans carrying loads in the center

span as shown in Fig. 1*a*. For an amount of end restraint of the center span and a load distribution which give larger moments M_A at the supports than center moment M_B (Fig. 1*b*) yield will first take place at the supports (Fig. 1*c*). Under further increase of load the center moment M_B will increase at a faster rate than in the elastic range to relieve the yielding sections at the supports. At the load P_1 these sections will have yield zones penetrating all the way to the neutral axis and can carry no additional moment until strain-hardening occurs. The center section, however, does not yield until the load reaches P_2, and loads P_p are required to produce yield all through the center section. Except for strain hardening the carrying capacity is now exhausted, and the center deflection (Fig. 1*d*) increases rapidly under practically no increase in load.

According to this concept, the theoretical collapse load is defined as that load at which a small load increment would cause a very large increase in deflection. As a practical substitute for the collapse load, a "full load" is selected as the load midway between the theoretical maximum and the load at which the last hinge starts to form. However, this simple definition of the full load is not concerned with the magnitude of the deflections at that load but merely with their rapid rate of change. The magnitude of the deformation at this full load may be prohibitive, and the structure in reality rendered useless at a lower load due to excessive deflections. In some cases, therefore, a design based on the ultimate carrying capacity requires the computation of the deflections at the full load. If this deformation cannot be tolerated as a limiting criterion, then the load causing the maximum tolerable deformation must be computed and substituted for the full load.

Admittedly, there are no numbers or rules which can be written down at this time that will indicate the limit of structural usefulness, i.e., the deflection that cannot be tolerated. Work at the Armour Research Foundation and described by Lurie[12*] has clearly shown that the current practice of limiting deflection to $^1/_{360}$ of the span length in order to prevent plaster cracking is not the result of a rational approach to the problem. A rational deflection limit must be based on other considerations than the cracking of plaster.

In order to make comparisons and to illustrate the principals, certain deflection limits at working load and at full load have had to be adopted in this paper. It must be emphasized, however, that their only value is to serve the above purpose.

A constant load factor for each type of structure leads to a uniform safety margin and thus to economy in design. In Progress Report No. 3 those items covered by the load factor were discussed. It was indicated that "a structure so designed will usually be loaded within the elastic limit in the range of its working load." However, since the reserve strength above the yield load varies greatly with the amount of end restraint and the type of load distribution, an economical load factor may under some conditions bring parts of the structure above the yield point under the working load. In these cases a check on the deflections under working load will be desirable.

The above discussion points out the need of methods for computing beam deflections beyond the elastic range. The simple linear relationship between load and deflections is lost as soon as initial yield is reached anywhere in the beam (Fig. 1*d*), consequently, the calculation of the deflections becomes more involved. It is a purpose of this paper to show the effect of various simplifying assumptions (outlined in Ref. 22) which can be made in order to reduce the work involved in such calculations, and also to indicate the influence on deflections of various end conditions and load distributions.

The underlying principles for predicting deflections in the plastic range were furnished by Nadai[13] and Timoshenko.[21] The latter, with references to earlier work, outlines an accurate semigraphical procedure based on the actual stress-strain relationship using the conjugate beam method and the concept of reduced modulus of elasticity. Van den Broek[19] gives examples of the calculation of beam deflections based on an idealized stress-strain diagram, and gives observed deflections of simple and continuous beams of steel and various alloys.

Roderick and Phillips,[11] in a literature survey on the carrying capacity of simply supported mild steel beams, compare the deflections according to various assumptions concerning the stress distribution through the depth of the beam, and derive the slope-deflection equations in the case of symmetrical concentrated loads.

Roderick,[16] using Timoshenko's semigraphical method, shows that the simple plastic theory based on an idealized stress-strain diagram determined from annealed specimens leads to a satisfactory prediction of the ultimate load. However, this theory does not predict with great accuracy the deflections of as-delivered specimens. In Reference 15 the simple plastic theory is extended to take into account strain hardening. Both these reports present results from simply supported, rectangular beam tests.

Symonds and Neal,[18] by means of the slope-deflection method, calculate the critical deflections according to the simple plastic theory for the load under which yielding starts at the last hinge to form (δ_2 in Fig. 1*d*). The predictions are compared with test results of Stüssi and Kollbrunner[17] (1935) and Maier-Leibnitz (1936) for 3-span beams of varying ratio between outer and center span lengths. Strain hardening and the spread of the plastic zones is not considered. These authors call for full-scale tests of frames and continuous beams made from standard commercial sections using normal fabrication procedures.

Such tests are in progress at Lehigh University as part of an investigation of welded continuous frames and their components. Results are reported for beams,[1, 5] columns,[3, 6] corner connections[4] and portal frames.[7] Reference 3 in this series shows that plastic design results in deflections which compare favorably with those resulting from elastic design, and suggests a simple method of drawing the load-deflection diagram for beams in the plastic range. In a discussion of this paper Symonds[20] suggests taking the deflection under working load as the deflection δ_2, when the last hinge starts to form, divided by the load factor. This approach, however, results in deflection estimates which may be several hundred percent too large.

Although beams only are discussed in this paper, the results may be extended to portal frames with small axial loads and no side sway. Experimental deflections from tests of miniature frames under various combinations of vertical and side loads are given by Baker and Heyman.[9] Hrennikoff[11] (and discussors) and Symonds[18] offer analytical solutions for the plastic deflections of frames.

LIMITATIONS

Several factors influencing the deflections of beams in the plastic range are not included in the following treatment. The most important of these factors are briefly discussed in the following.

Local Instability

The usual rolled sections are so proportioned as to prevent local buckling of their elements in the elastic region. When part of a cross section has yielded, however, the resistance against local buckling of the compression flange at that cross section is reduced. Local instability therefore may cause greatly increased deflections and collapse before the beam is stressed very far into the plastic range.

Plastic design theories are based on the assumption that the sections used have sufficient "rotation capacity" to allow the plastic hinge moment to be maintained through the required localized angle of rotation necessary for development of hinge moments at all other required locations. Premature local buckling of cross section elements will destroy the rotation capacity and thus invalidate the above basic assumption.

Residual Stresses

As-delivered beams show large "locked-

* Numbers refer to list of References at the end of paper.

up" or residual stresses due primarily to nonuniform cooling after hot rolling. The process of straightening or cambering after rolling and also welding has a similar although more localized effect.

When added to the stresses produced by external loads the residual stresses lower the yield load on a structure appreciably below that expected from simple tension tests.[8] A reduction of the calculated initial yield load by one-third is commonly found. This earlier yield causes deflections somewhat larger than predicted.

Stress Concentrations

Stress concentrations in the region of application of concentrated loads are generally not considered in the analysis, and raise the actual peak stresses far above the computed nominal stresses. As a result, yield occurs at lower loads than predicted and is more extensive, thus causing a corresponding increase of actual deflections.

Shear Deformation

As is common procedure in calculating elastic deformations, the effect of shear forces is neglected. However, yielding of the web due to shear force may add appreciably to the beam deflections.

Axial Compressive Forces

Although only beams are treated in this paper the numerical examples simulate pin-ended portal frames without side sway. If the outer spans were rotated about the interior supports to a vertical position, they would then form the legs of the portal frame. In such frames, however, all members carry compressive axial forces in addition to moments, the effect of which is two-fold:

1. For a certain moment the addition of a compressive axial force increases the curvature of the member, thus increasing the deflection. This effect is minor for thrusts smaller than about 10% of the compressive yield load.
2. As deflections grow larger the additional moment of the thrust multiplied by the deflection becomes appreciable. For one of the portal frame tests in which a uniform 8WF40 section was used, this effect added 11% to the maximum beam moment at the ultimate load. The deflections are correspondingly increased.

Catenary Effect

Large deflections tend to shorten the distance between supports. In beams with pinned supports axial tensile stresses develop and a part of the load is carried through this catenary effect with resulting smaller deflections than if carried by bending.

In portal frames as discussed above the knees are practically free to approach one another, and the axial tension does not develop.

Summary of Limitations

The integrated effect of local instability, residual stresses, stress concentrations, shear deformation and thrust is to increase the deflections and lower the ultimate carrying capacity. Reference 5 offers a more detailed discussion of these factors on the background of experimental evidence, which is summarized as follows:

1. The calculated deflection at the predicted initial yield load was reached at a 10 to 25% lower load.
2. At the calculated initial yield load the deflections exceeded those predicted by 13 to 88%.

Common to all of the methods for calculating plastic deflections discussed in this paper are the following basic assumptions.

1. The longitudinal strain varies linearly across the depth of the beam.
2. The stress-strain relationship in bending is identical to that in simple tension tests.
3. The stress-strain relationship is the same in tension as in compression.
4. Under increasing load the ratios between the individual loads are held constant.

METHODS FOR COMPUTATION OF DEFLECTIONS

In the elastic theory the linear relation between bending moment and curvature is expressed by

$$\phi = \frac{M^*}{EI} \qquad (1)$$

* See page 251-s for "Nomenclature."

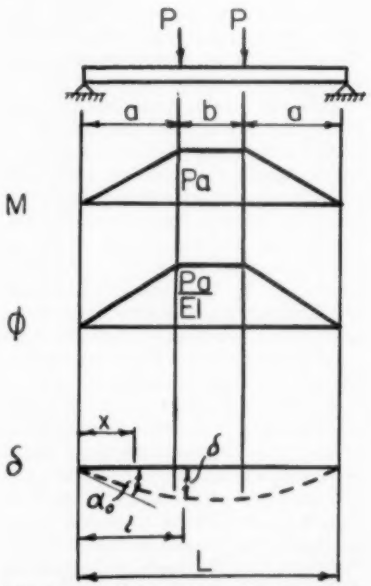


Fig. 2 Load-deflection relationship in the elastic range

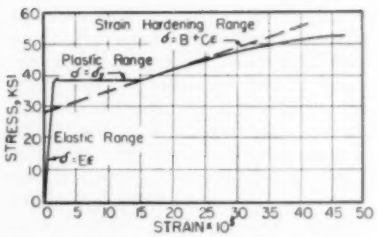


Fig. 3 Measured and idealized stress strain diagram

The change in slope of the deflected beam between $x = 0$ and $x = x$ equals the area under the ϕ-curve between these points:

$$\alpha_0 - \alpha = \int_0^x \phi \, dx \qquad (2)$$

In the example in Fig. 2, α_0 is the slope at the left support and is found by the "conjugate beam" method:

$$\alpha_0 = \frac{1}{L} \int_0^L \phi(L - x) \, dx \qquad (3)$$

The deflection δ at a distance l from the support, Fig. 2, then becomes

$$\delta = \int_0^l \alpha \, dx = \alpha_0 l - \int_0^l \phi(l - x) \, dx \qquad (4)$$

which may be interpreted as the moment of the area under the ϕ curve between $x = 0$ and $x = l$ about the point of δ, including the effect of the slope at the support.

Above the elastic limit the linear relationship eq 1 is lost, but the same method as outlined above holds if the actual M-ϕ relationship is used in place of eq 1. Assuming the same stress-strain relationship in bending as determined from simple tension tests, Fig. 3, the M-ϕ diagram may be derived from the stress-strain diagram as outlined in the appendix of Reference 1. In Fig. 3 the measured stress-strain curve is closely approximated in the elastic range by

$$\sigma = E \cdot \epsilon \qquad (5)$$

in the plastic range for as-delivered steel having no distinct upper yield point by

$$\sigma = \sigma_y \qquad (6)$$

and in the early part of the strain-hardening range by

$$\sigma = B + C\epsilon \qquad (7)$$

The latter part of the strain-hardening range will rarely be reached due to failure by local buckling, and is of little practical interest.

The M-ϕ diagram evaluated from this stress-strain relationship for an 8WF40 section is shown in Fig. 4. Using such a M-ϕ relationship in place of eq 1 the deflections above the elastic range may be calculated by the procedure exemplified in eqs 2 to 4. In statically determinate beams no difficulties are encountered, but for redundant beams the nonlinear M-ϕ relationship necessitates a trial-and-error procedure to satisfy the boundary conditions.

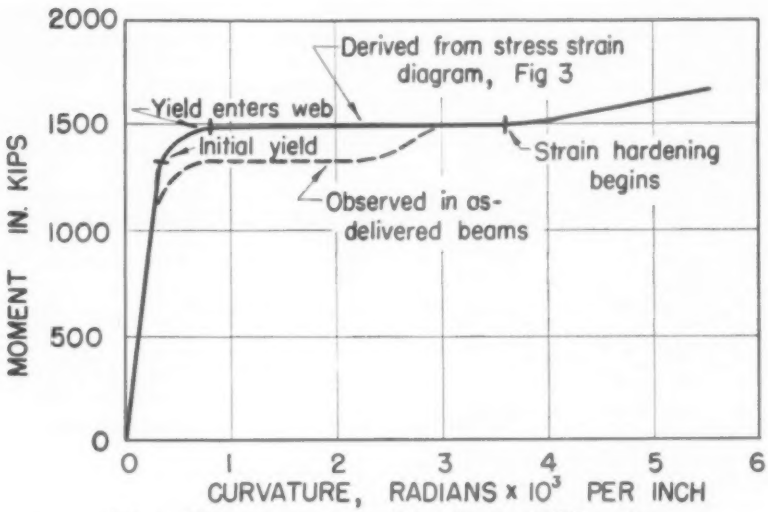


Fig. 4 Moment-curvature relationship for 8WF40 section

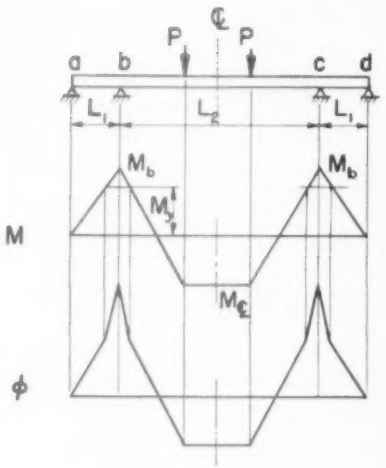


Fig. 5 Moment and rotation diagrams for a plastically bent beam

In the example of Fig. 5 (a symmetric, continuous beam with third-point loads in the center span), the yield moment is exceeded at supports and the ratio between the moments at support M_c and at the centerline $M_{\text{℄}}$ is no longer given by the elastic analysis. With an assumed value of M_b the centerline moment is given by

$$M_{\text{℄}} - M_b = \frac{PL_c}{3} \qquad (8)$$

and the ϕ-diagram can be plotted as shown using an M-ϕ curve like Fig. 4. Due to symmetry, the rotation of the beam axis at the center as determined by integration of the ϕ-diagram should be zero. This boundary condition will most likely not be satisfied by the first trial assumption for M_b. The zero-line of the moment diagram must then be shifted in the proper direction, the new ϕ-diagram plotted, its areas computed and a second check on the resulting rotation at the centerline obtained. The method is theoretically satisfactory but the amount of numerical work involved is prohibitive for practical applications.

In principle the above approach is common to the various methods. The meth-

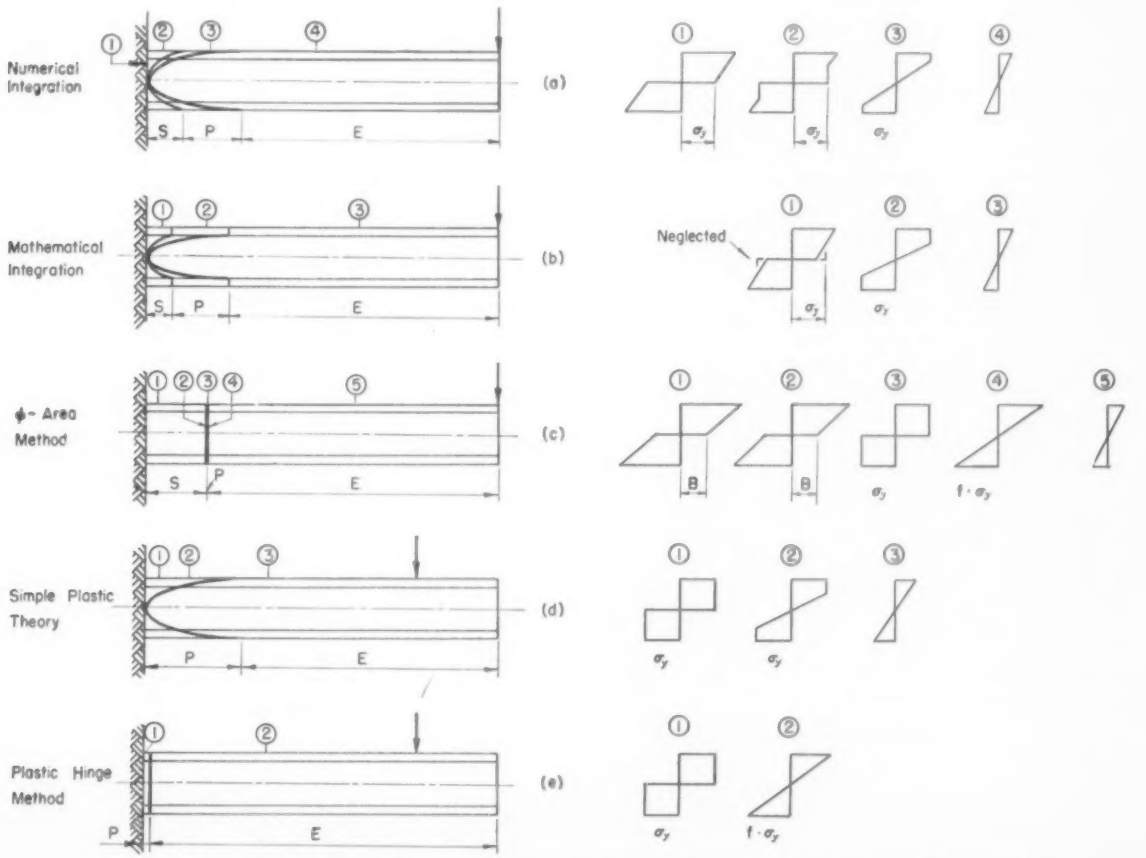


Fig. 6 Stress distributions in beams above the elastic range assumed in the methods discussed

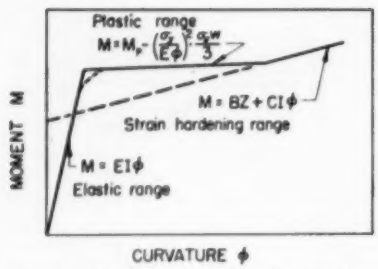


Fig. 7 Idealized M-φ curve for mathematical integration method

ods differ only in the extent to which simplifying assumptions are made in order to reduce the amount of work involved.

(a) Numerical Integration of the Actual M-φ Curve

This method is outlined above and gives the exact deflection in so far as the M-ϕ diagram used is correct. In as-delivered specimens, however, residual stresses and stress concentrations will cause earlier yield and delay the attainment of the predicted "plastic hinge moment" as indicated in Fig. 4. In comparison with this effect the simplifying assumptions employed in the following methods introduce relatively small errors.

The actual stress distribution across and along the beam as illustrated for a cantilever in Fig. 6*a* forms the basis for this "exact" method.

(b) Mathematical Integration of Idealized M-φ Curve

This method is due to W. H. Weiskopf and is described by him in the Appendix of this paper. Mathematical integration of the M-ϕ curve is made possible by the idealization shown in Fig. 7. The resulting assumption of stress distributions in a beam is shown in Fig. 6*b*.

The effect of neglecting the short curved portion of the M-ϕ diagram near the yield point (Fig. 7) is to slightly reduce the predicted deflections. This error becomes larger for sections having large relative flange thickness, especially if a considerable length of the beam is under constant moment. Neglecting the small triangles in stress diagram 1, Fig. 6*b*, also reduces the calculated deflections, but in significant amounts only for deep I-sections and rectangular sections.

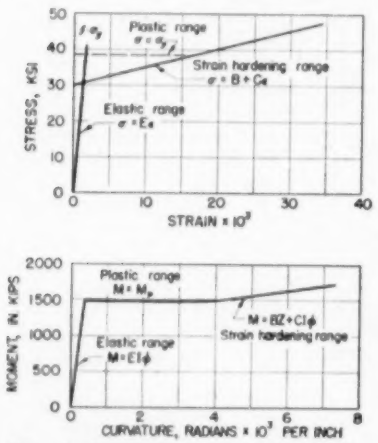


Fig. 8 Stress-strain and M-φ relationships assumed in φ area method

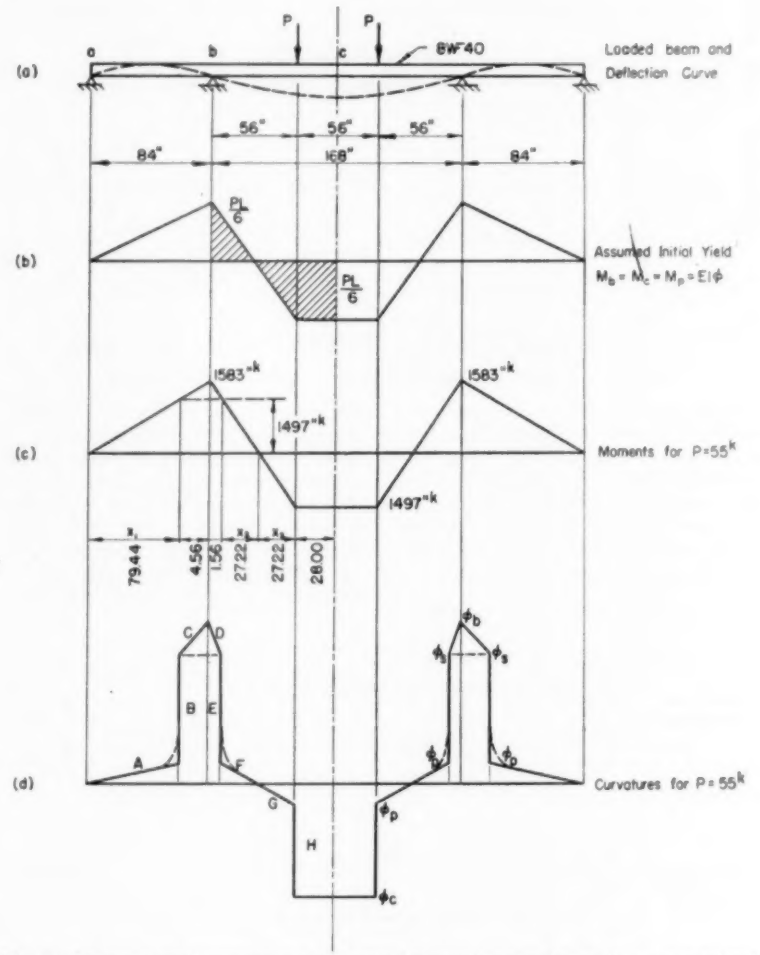


Fig. 9 Moment and curvature diagrams for continuous beam (φ-area method)

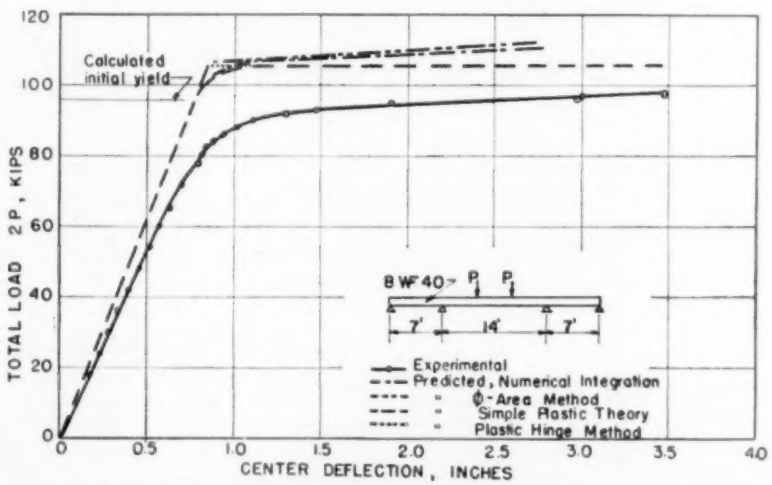


Fig. 10 Load-deflection relationship of a continuous beam

(c) ϕ-Area Method

C. H. Yang[22] suggested the further simplification of neglecting the spread of the plastic zones along the length of the beam. The equivalent assumption for the stress-strain and M-ϕ relationships are shown in Fig. 8. In a beam with a moment gradient as shown in Fig. 6c the length of the perfectly plastic region will consequently be zero. The curvature in the remaining two regions is related to the moment by

$$\phi = \frac{M}{EI} \qquad (9)$$

in the elastic region up to M_p, and

$$\phi = \frac{M - BZ}{CI} \qquad (10)$$

in the strain-hardening region for moments exceeding M_p (Fig. 8). In a region of constant moment M_p the curvature will have a value between the limits

$$\frac{M_p}{EI} \leq \phi \leq \frac{M_p - BZ}{CI} \qquad (11)$$

and is determined by the boundary conditions.

The effect of neglecting the spread of the plastic zone along a member with a moment gradient is to give somewhat smaller predicted deflections. This additional simplifying assumption thus adds to the inaccuracies of the previous method, but the deviations are small as compared to the influence of residual stress and stress concentration as indicated on the M-ϕ diagram, Fig. 4. These assumptions considerably shorten the numerical work, as is shown by the following example when compared with the Appendix.

Consider an 8WF40 beam over three spans 7, 14 and 7 ft, with concentrated loads P at the third-points of the central span (Fig. 9a). The maximum deflection (which occurs at the centerline) will be calculated. The material properties and the geometrical properties of the 8WF40 section as determined by tests[5] are shown in Table 1.

From the elastic analysis of the structure we have

$$M_c = -M_b = \frac{PL}{6} \qquad (12)$$

where M_c and M_b are, respectively, the moments at centerline and support. Elastic behavior is assumed until these moments reach the full plastic hinge value M_p (Fig. 9b), corresponding to the load

$$P = \frac{6M_c}{L} = -\frac{6M_b}{L} = \frac{6M_p}{L} = 53.5 \text{ kips} \qquad (13)$$

The curvature at any point is proportional to the ordinate of the moment diagram, Fig. 9b. The beam axis at the center remains horizontal due to symmetry, and the center deflection equals the moment about the support b of the shaded area of the ϕ-diagram, Fig. 9b:

$$\delta_c = \frac{1}{EI}\left[\frac{M_pL}{2}\cdot\frac{L}{4} - \frac{1}{2}\cdot\frac{2M_pL}{3}\cdot\frac{L}{9}\right] = \frac{19}{216}\frac{M_pL^2}{EI} = 0.85 \text{ in.} \qquad (14)$$

A further increase in the loads P will cause yield both at center and support. Strain hardening will commence at the supports, but the center moment will not increase until the curvature is increased $\phi_s/\phi_y = 11.5$-fold (Table 1). Thus for loads, say $P = 55$ kips (Fig. 9c),

$$M_c = 1497 \text{ in-kip}$$

$$M_b = \frac{PL}{3} - M_c = 1583 \text{ in-kip}$$

The points where the moment reaches $M_p = 1497$ in-kip on either side of the supports are easily determined (Fig. 9c):

$$x_1 = \frac{1497}{1583}\cdot 84 = 79.44 \text{ in.}$$

$$x_2 = \frac{M_p}{P} = \frac{1497}{55} = 27.22 \text{ in.}$$

Table 1—Properties of 8WF40 Section[5]

Material Properties (Measured)			
Young's modulus of elasticity, psi	E	=	29.6×10^6
Yield point (lower), psi	σ_y	=	37,760
Strain-hardening offset (Fig. 8), psi	B	=	28,560
Strain-hardening modulus (Fig. 8), psi	C	=	630
Geometrical Properties of 8WF40 Section (Measured)			
Flange width, in.	b	=	8.06
Flange thickness, in.	t	=	0.552
Depth, in.	d	=	8.32
Web thickness, in.	w	=	0.370
Cross-section area, in.^{2}	A	=	11.66
Section modulus (strong axis), in.^{3}	S	=	35.34
Plastic modulus (strong axis), in.^{3}	Z	=	39.65
Moment of inertia (strong axis), in.^{4}	I	=	147.0
Shape factor	f	=	1.122
Section Properties of 8WF40 Section (Derived from Above)			
Yield moment, in-kips	M_y	=	1334
Plastic hinge moment, in-kips	M_p	=	1497
Curvature at initial yield, rad./in.	$\phi_y = \frac{M_y}{EI}$	=	307×10^{-6}
	$\phi_p = f\cdot\phi_y$	=	344×10^{-6}
Curvature at which strain hardening begins, rad./in.	$\phi_s = \frac{M_p - BZ}{CI}$	=	3944×10^{-6}
	$\frac{M_yL^2}{EI}$	=	9.653 in.
	$\frac{M_pL^2}{EI}$	=	9.710 in.

Using eqs 9 to 11 or Fig. 8 the corresponding curvature diagram, Fig. 9d, can be plotted. The characteristic rotations are:

$$\phi_p = \frac{M_p}{EI} = 344 \cdot 10^{-6} \text{ rad/in.}$$

$$\phi_s = \frac{M_p - BZ}{CI} = 3944 \cdot 10^{-6} \text{ rad/in.}$$

$$\phi_b = \frac{M_b - BZ}{CI} = \frac{1583 - 1132}{630 \times 147} = 4870 \cdot 10^{-6} \text{ rad/in.}$$

The curvature ϕ_c in the center region is of a magnitude between ϕ_p and ϕ_s corresponding to the horizontal part of the M-ϕ diagram, Fig. 8. Its value must be determined using the condition of zero slope of the beam axis at the centerline, $\alpha_c = 0$. In this example only the area H of the curvature diagram Fig. 9d depends on ϕ_c, which then in the following computation is determined to give $\alpha_c = 0$.

It is seen that the magnitude of the

		Area of ϕ-diagram		*Moment arm to "a"*		*Moment about "a"*
A	$= -\frac{1}{2} \times 79.44 \times 0.000344 =$	-0.0137	$\times$	52.96	=	-0.725
B	$= -\quad 4.56 \times 0.003944 =$	-0.0180	$\times$	81.72	=	-1.471
C	$= -\frac{1}{2} \times 4.56 \times 0.000926 =$	-0.0021	$\times$	82.48	=	-0.173
						-2.369
				Moment arm to "b"		*Moment about "b"*
	$\alpha_b = -\frac{2.369}{84} =$	-0.0282				
D	$= -\frac{1}{2} \times 1.56 \times 0.000926 =$	-0.0007	$\times$	0.52	=	-0.009
E	$= \quad 1.56 \times 0.003944 =$	-0.0062	$\times$	0.78	=	-0.005
F	$= -\frac{1}{2} \times 27.22 \times 0.000344 =$	-0.0047	$\times$	10.63	=	-0.050
G	$= +\frac{1}{2} \times 27.22 \times 0.000344 =$	$+0.0047$	$\times$	46.93	=	$+0.221$
H	$= \quad 28.00 \times 0.001254 =$	$+0.0351$	$\times$	70.00	=	$+2.457$
	$\alpha_c =$	0		δ_c	=	2.62 in.

curvature of the yielded center portion of the beam, consistent with the condition $\alpha_c = 0$, is found to be

$$\phi_c = 0.001254 \text{ rad/in.}$$

The centerline deflection for $P = 55$ kips then is $\delta_c = 2.62$ in. or $^1/_{44}$ of the span length. It follows that strain hardening in the center portion corresponding to

$$\phi_c = 0.003944 \text{ rad/in.}$$

will not take place while the deflections are tolerable and often will never be reached due to earlier collapse caused by local compression flange buckling.

Additional points on the load-deflection curve may be obtained in the same manner, but the relationship is very nearly linear above the yield point until strain hardening would commence. The curve is plotted in Fig. 10 in comparison with predictions by numerical integration and the simple plastic theory. The results from these three methods fall close together which indicate that the simplifications of the theoretical M-ϕ curve, Fig. 4, are of small consequence. However, all three curves give smaller deflections than those obtained experimentally.[5] As discussed earlier, the discrepancy is due to the fact that the theoretical M-ϕ relationship derived from the stress-strain curve fails to give precise results for as-delivered members.

Much closer agreement with the experimental deflections are obtained when there is no portion of the beam under constant moment as shown for a cantilever in Fig. 11. In such a case a large portion of the beam is actually in the transition (elastic-plastic) range which is influenced by the assumptions made. This figure, taken from Reference 22, shows very good agreement with tests except in the early part of the plastic region. At this load level the effect of residual stresses and stress concentration must be expected to be most pronounced.

(d) *The Simple Plastic Theory*

The simple plastic theory neglects the strain hardening effect, but considers the spread of the plastic zones along the member. Fig. 6*d* shows the assumed stress distribution in a cantilever according to this theory. The calculation of deflections is further simplified over the previous methods.

Using again the example of Fig. 9, the load and deflection at initial yield are obtained by eqs 13 and 14 with M_y instead of M_p:

$$P_y = \frac{6M_y}{L} = 47.6 \text{ kips}$$

$$\delta_y = \frac{19}{216}\frac{M_y L^2}{EI} = 0.76 \text{ in.}$$

When the full plastic hinge moment is reached,

$$P = \frac{6M_p}{L} = 53.5 \text{ kips}$$

and deflections increase without limit since no further resistance is offered at the yielding sections.

Intermediate points on the load-deflection curve may be found by a numerical method similar to that used for the previous case except that the transfer from elastic to plastic behavior is gradual as shown by the dotted lines in Fig. 9*d*. The resulting curve is shown in Fig. 10 and is hardly distinguishable in the early plastic region from that determined by the more exact numerical integration method. Figure 11 shows the same result for a cantilever. The neglect of strain hardening results in a horizontal line at $P = P_p$.

In order to demonstrate this method in greater detail the computation of the center deflection of a built-in beam with third-point loading will be shown. The resulting load-deflection curve is given in Fig. 12 in comparison with experimental values and predictions by other methods.

Initial yield takes place when the largest elastic moment, at the fixed ends, reaches $M_y = 1334$ in-kips (Table 1). The loads are then

$$P_y = \frac{9}{2}\frac{M_y}{L} = 35.8 \text{ kips}$$

Handbook value,

$$\delta_y = \frac{5}{144}\frac{M_y L^2}{EI} = \frac{5}{144}\,8.653 = 0.30 \text{ in.}$$

Next, determine the point on the load-deflection curve corresponding to yielded flanges at the fixed ends (Fig. 1*d*):

$$M_F \approx M_p = 1497 \text{ in-kip (Table 1)}$$

$$M_{\mathbb{C}} = {}^1/_3 P_1 L - M_F = 56P_1 - 1497$$

Here, the unknown value P_1 is determined by the condition of zero resultant change in slope from the fixed end to the beam center. This condition is most easily

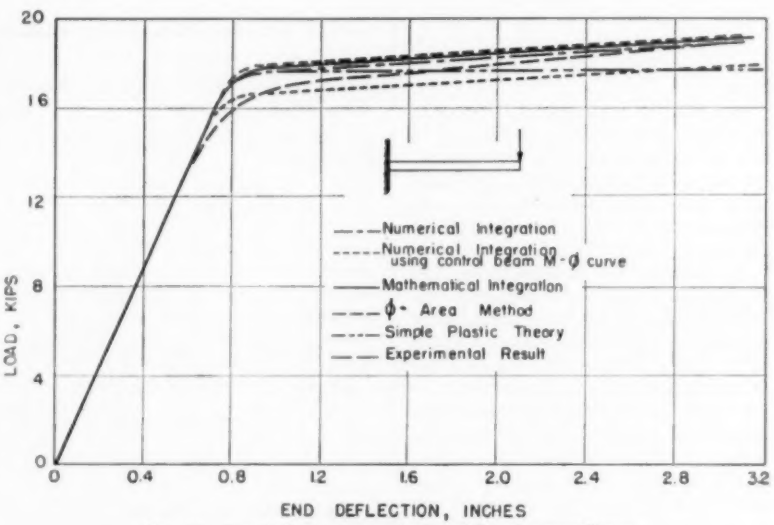


Fig. 11 Load-deflection relationship of a cantilever

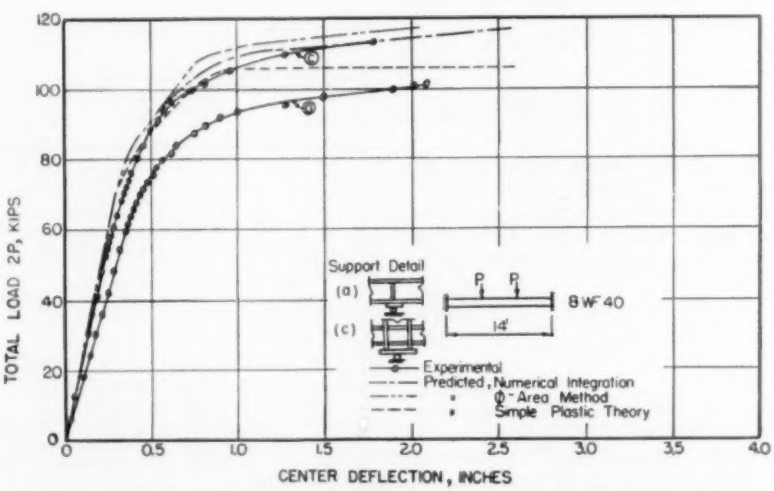


Fig. 12 Load-deflection relationship, fixed-ended beam

satisfied by a trial-and-error procedure, assuming a value for $M_{\text{℄}}$. After exceeding the yield load ($M_{\text{℄}} = 667$ in-kips) this moment is increasing at a more rapid rate than M_F. Thus, $M_{\text{℄}} = 850$ in-kips is assumed in the first trial, giving the curvature-diagram shown in Fig. 13. The curvature-producing yield through the flanges is

$$\phi_p' = \frac{d}{d-2t}\cdot\phi_y = 35.4\cdot10^{-6}\ \text{rad/in.}$$

Assuming the area (a) to be trapezoidal the total rotation from support to centerline is (Fig. 13):

ϕ area (a): $0.5\cdot(354+307)\,3.9\cdot10^{-6} = 1290\cdot10^{-6}$ rad.
ϕ area (b): $0.5\cdot307\cdot31.8\cdot10^{-6} = 4880\cdot10^{-6}$ rad.
ϕ area (c): $-0.5\cdot195\cdot20.3\cdot10^{-6} = -1980\cdot10^{-6}$ rad.
ϕ area (d): $-195\cdot28.0\cdot10^{-6} = -5469\cdot10^{-6}$ rad.
$-1370\cdot10^{-6}$ rad. $\neq 0$

Thus the centerline moment is smaller than assumed above, and the new value $M_{\text{℄}} = 750$ in-kips is tried. The corresponding coordinates are shown without parentheses on the ϕ-diagram, Fig. 13.

ϕ area (a): $0.5\cdot(354+307)\,4.0\cdot10^{-6} = 1320\cdot10^{-6}$ rad.
ϕ area (b): $0.5\cdot307\cdot33.0\cdot10^{-6} = 5110\cdot10^{-6}$ rad.
ϕ area (c): $-0.5\cdot172\cdot18.7\cdot10^{-6} = -1610\cdot10^{-6}$ rad.
ϕ area (d): $-172\cdot28.0\cdot10^{-6} = -4820\cdot10^{-6}$ rad.
$30\cdot10^{-6}$ rad.

The error is very small, and

$$M_{\text{℄}} = 750 + (850-750)\,\frac{30}{1370+30} = 752\ \text{in-kips},$$

by straight-line interpolation, is taken as the final value. Then

$$P_1 = \frac{3}{L}(M_F + M_{\text{℄}}) = \frac{1}{56}(1497+752) = 40.2\ \text{kips}$$

The corresponding center deflection δ_1 equals the moment of the ϕ-diagram (Fig. 13) about the centerline:

	ϕ Area, rad.	Moment arm, in.	Deflection, in.
(a)	$94\cdot10^{-6}$	82.7	0.008
	$1228\cdot10^{-6}$	81.9	0.101
(b)	$5110\cdot10^{-6}$	68.9	0.352
(c)	$-1610\cdot10^{-6}$	34.2	−0.055
(d)	$-4820\cdot10^{-6}$	14.0	−0.007
			$\delta_1 = 0.34$

From (P_1, δ_1) the load-deflection curve closely parallels that of a simply supported beam

$$\delta_2 - \delta_1 = \frac{7}{216}\,\frac{(P_2-P_1)L^3}{EI}$$

until the moment in the center region reaches the yield moment $M_y = 1334$ in-kips which occurs for

$$P_2 = \frac{3}{L}(M_F+M_{\text{℄}}) = \frac{3}{L}(M_p+M_y) = \frac{1497+1334}{56} = 50.6\ \text{kips}$$

The deflection is then, from the equation above,

$$\delta_2 = \delta_1 + \frac{7}{216}\,\frac{(P_2-P_1)L^3}{EI} = \delta_1 + \frac{7}{216}\cdot\frac{9}{2}\cdot\frac{P_2-P_1}{P_y}\cdot\frac{M_yL^2}{EI} =$$

$$0.34 + 0.146\cdot\frac{10.4}{35.8}\cdot8.653 = 0.71\ \text{in.}$$

Finally, the carrying capacity is very nearly exhausted when yield has penetrated through the flanges also at the center section which occurs for a load negligibly smaller than

$$P_p = \frac{3}{L}\cdot2M_p = \frac{2.1497}{56} = 53.5\ \text{kips}$$

The curvature between load points is now $\phi_p' = 354\cdot10^{-6}$ rad/in., while the curvature at the fixed ends is larger and can be determined by the continuity condition of zero resultant change in slope from support to beam center. From the ϕ-diagram thus determined the center deflection is found following the procedure that gave δ_1 above. At this point the deflection, neglecting strain hardening and catenary effect, becomes indeterminate and the beam deflects without limit under constant loads P_p.

(e) *Plastic Hinge Method*

Figure 6e shows a stress distribution in which yielding is assumed to be limited to the cross section which first reached initial yield. This assumption differs only from the simplified method of mathematical integration, Fig. 6c, in that strain hardening is neglected. The beam has elastic regions and localized plastic hinges only, and the M-ϕ relationship consists of the two straight lines $M = EI\phi$ in the elastic range and $M = M_p$ in the plastic range.

The member is assumed to behave elastically until a maximum stress $f\cdot\delta_y$ is reached (f is the shape factor). This is equivalent to assuming that all of the material is concentrated in a line at the flange. In the example Fig. 9, the stress $f\cdot\delta_y$ corresponds to a load

$$P = \frac{6M_p}{L} = 53.5\ \text{kips}$$

and a deflection at the centerline of

$$\delta = \frac{19}{216}\,\frac{M_pL^2}{EI} = 0.85\ \text{in.}$$

(eqs 13 and 14). The sudden formation of a plastic hinge at that load causes a sharp break in the load-deflection curve, Fig. 10.

This simple approach was suggested in Reference 3, and is illustrated in Appendix

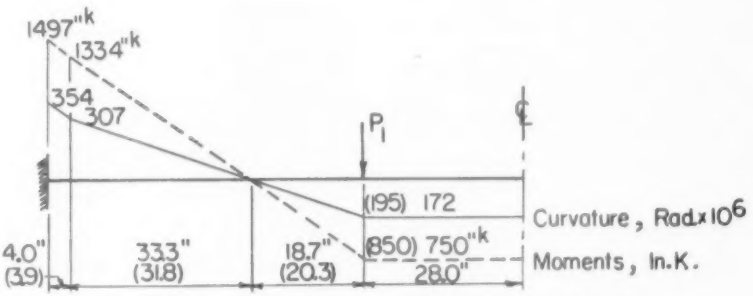


Fig. 13 Moment and ϕ-diagram under assumed load P_1

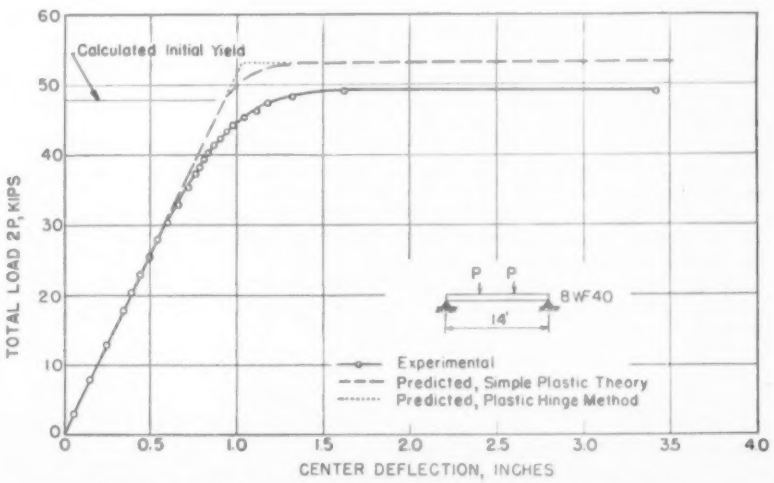


Fig. 14 Load-deflection relationship, simply supported beam

C of that reference by the case of a fixed-ended beam with a concentrated load off center. This method obviates the necessity of knowing the M-ϕ relationship above the elastic range, and makes use of deflection formulas usually available in the design office and tabulated in structural handbooks.

COMPARISON WITH EXPERIMENTAL RESULTS

Comparisons of the predicted and experimental deflections for a continuous beam and for a cantilever are given in Figs. 10 and 11, respectively, which were previously discussed.

Figure 12 shows a similar comparison for an 8WF40 beam with fixed ends and third-point loading. As in the case of the continuous beams, Fig. 10, the differences in the predictions resulting from the various methods outlined above are smaller in the early plastic range than the deviation from the test results for the beam with detail (*a*) (Fig. 12) at the supports which were also used in the tests in Figs. 10 and 14. Detail (*c*) gives a stiffer beam with deflections in close agreement with predictions. The deflections derived by mathematical integration are not shown, but would fall between the two upper curves. The plastic hinge method would give a curve following the simple plastic theory curve except for sharp knees at the two curved regions.

Figure 14, finally, compares computed and experimental[5] deflections for a simple beam under third-point loading. Strain hardening theoretically does not begin until the center deflection reaches about 8 in. and all methods give deflections falling on the curve shown for the simple plastic theory, the sharp knee of the plastic hinge method excepted. In the test, yielding started at about one-third of the calculated initial yield load, causing larger deflections than those predicted.

The comparison with tests, Fig. 10–14, indicates that hardly any advantage is gained by using the more refined and laborious methods outlined above for predicting deflections. The amount of work involved in a case like the continuous beam of Fig. 9 by the methods (*a*) to (*c*) is, very roughly, in the ratios 5:4:3:2:1 and these ratios rapidly grow larger with more complicated problems.

The comparisons of Figs. 10, 12 and 14 with experimental results are unfavorable due to the large influence of residual stresses over the length of the beams under constant moment. The agreement in Fig. 11 for the cantilever is more typical for most practical cases.

For engineering purposes the plastic hinge method probably would be preferred. The other methods belong in the research field where greater accuracy is often required to explain experimental behavior.

The inclusion in the calculation of deflections of strain hardening, although laborious, does not necessarily yield a truer answer since earlier failure due to local buckling is probable in many cases. In cases where strain hardening does occur but is neglected, the estimates of both the ultimate load and the deflections will be on the safe side.

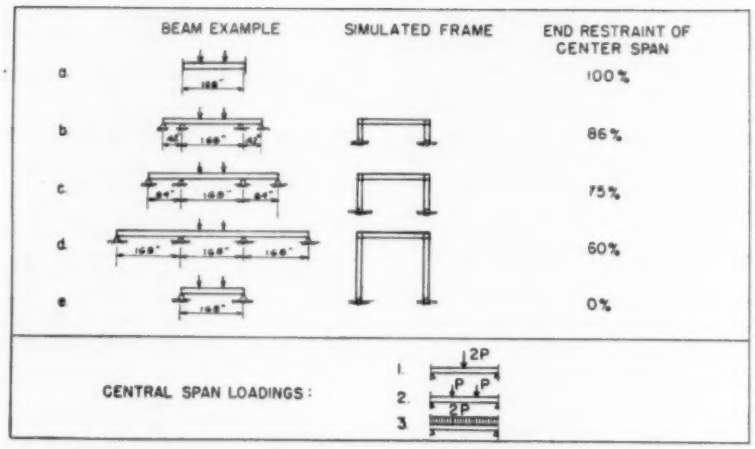


Fig. 15 Illustrative examples of effect on maximum beam deflections of end restraint and load distribution

INFLUENCE OF END RESTRAINT

As a member of a structural frame or part of a continuous beam, a single beam span may have any amount of end restraint between fully fixed and simply supported. Certain loading combinations on a beam span and its neighboring spans may even cause end moments in excess of those encountered for full fixity. Such increases in end restraint are associated with a decrease in the midspan deflection. The distribution of the live load on the span may also vary, and is usually somewhere between uniform distribution over the whole span and concentrated center loading.

In order to illustrate the effect of end restraint and load distribution, a series of examples as shown in Fig. 15 is chosen and the load-deflection curves computed by the simple plastic theory. The end restraint on the center span imposed by the outer spans varies in these examples from 100% (full fixity) through 86, 75 and 60% to the case of the simple span.

The frames simulated by the continuous beams are indicated in Fig. 15. Of these, Frame (*c*) has been tested as such.

Three loading conditions as shown in Fig. 15 are investigated: (1) A concentrated load $2P$ at center; (2) third-point concentrated loads P; (3) uniform load $W = 2P$. An 8WF40 section was used throughout these examples. The section properties are listed in Table 1.

The load-deflection curves for the 5 deg of end restraint are shown in Fig. 16 for the case of a concentrated load at the beam center. According to the simple plastic theory, the ultimate carrying capacity is 71.3 kips for any degree of end restraint different from 0%. In the latter case the ultimate load is reduced to one half of that value. Thus, there appears to be an illogical discontinuity in the value of the ultimate carrying capacity when the end restraint is increased from zero.

Figure 16 shows, however, that the ultimate load according to the simple plastic theory should not be taken as a design

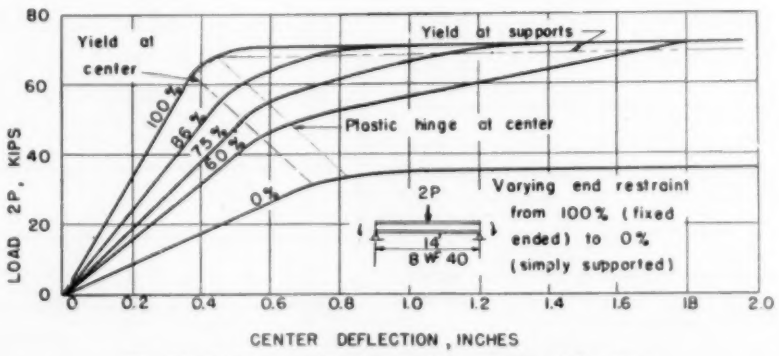


Fig. 16 Influence of end restraint on beam deflections

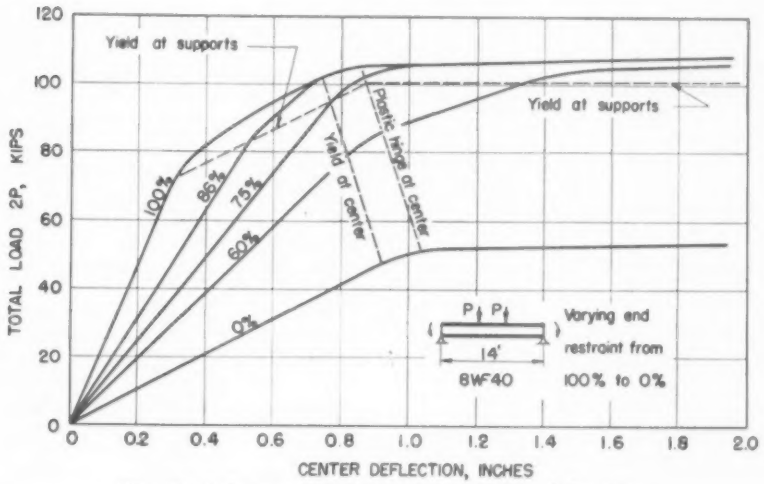


Fig. 17 Influence of end restraint on beam deflections

criterion for beams with small end restraints. Very large deflections, which cannot be tolerated as a limit criterion for structural usefulness, will take place before this "ultimate load" is attained. Also, local flange buckling will bring about collapse before extreme deflections are reached. Safe and tolerable limits, for the deflection under the "full load" (working load multiplied by the load factor), must therefore be imposed.

The load-deflection curves for the beams of Fig. 15 with third-point loading on the center span are shown in Fig. 17, and with uniform load on the center span in Fig. 18. The discussion above applies also for these loading cases. For small end restraints, the ultimate load will not be reached and the corresponding deflections could not be tolerated as the limit of structural usefulness.

For the purpose of the following example assume these specifications for plastic design of continuous beams:

(*a*) Load Factor of 1.65 based on $M_0 = 1/2\,(M_p + M_y)$ at the last hinge to form. This possibility was suggested in an earlier paper.[3]

(*b*) Maximum deflection at full load arbitrarily selected at $L/100$.

Beams with a concentrated load at the center and end restraint varying from 0 to 100% of fixity have been analyzed for these specifications. The resulting carrying capacities are given in Table 2. For end restraints larger than 65% specification (*a*) limits the working load. Below that value specification (*b*) applies as is shown under "Deflection at full load" in Table 2. The effect is to give gradual reduction in working load as the end restraint decreases to zero (the simple beam). The last two columns of Table 2 afford a comparison with elastic design, the elastic design working load being taken as $P_w = P_y/1.65$.

Thus, plastic design results in an increase in working load from 5 to 33% over the elastic design. It should be noted, however, that a part of this gain is due to the choice of a different basis for the full load in the two design methods. On a strict comparative basis, therefore, $0.5 \cdot (f - 1) \cdot 100\%$ should be subtracted from those numbers in the last column of Table 2 which are determined by P_{ult}, giving a gain of 0–29% resulting from plastic design.

Figure 19 shows the load-deflection curves for these beams according to the plastic hinge method, and in Fig. 20 are given the similar curves for the case of uniformly distributed load. The upper limits for allowable working loads according to the plastic and elastic analyses outlined above are indicated in the figures. The working loads resulting from the plastic analysis are everywhere within the elastic limit. This is a point about which there has been considerable discussion. The area between the lines showing the elastic and plastic working loads indicates the economy resulting from the latter.

A possible additional specification:

(*c*) Maximum deflection at working load limited to, say, $L/360$.

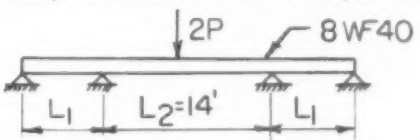
would decrease the working loads as indicated in Figs. 19 and 20. Since this specification is more rigid than the limitation used here for deflection at full load the calculation of the latter could be omitted. It is obvious that this simplification would hold generally for symmetric continuous beams with any degree of end restraint and symmetric load distribution since the examples in Figs. 19 and 20 cover the complete range of end restraints and the critical loading case. Thus, symmetrically loaded continuous beams can be designed on the basis of full load and elastic deflection under working load. However, for other types of structures, like frames subjected to side loads, it may be necessary to revert to specification (*b*) above.

It is doubtful whether, in continuous engineering structures, end restraints in the lower range (0–50%) will be encountered. If this is true it may be that specification (*b*) has no practical application.

The purpose of the above analysis is not to advocate unrestricted use of plastic design, but merely to show its possible advantage where the limitations as mentioned earlier do not prohibit its application.

The magnitude of the load factor and the magnitude of the allowable deflection at working and full load are matters for discussion. It is emphasized that the deflection limitations $L/100$ and $L/360$ are purely arbitrary. Whatever deflection limitations are established should provide

Table 2—Working Loads and Theoretical Deflections of Continuous Beams Designed by Elastic and Plastic Theories (from Fig. 19)



End restraint		Plastic design			Elastic design	Increase in working load (plastic over elastic),
	L_1/I_2	Working load 2P, kips	Deflection at working load $\times L_2$	Deflection at full load $\times L_2$	Working load, kips	
%						%
100	0	40.8	1/730	1/410	38.6	5
90	0.17	42.0	1/540	1/250	34.0	17
80	0.38	42.0	1/440	1/170	32.0	24
70	0.64	42.0	1/370	1/120	29.6	30
65	0.81	42.0	1/340	1/100	28.5	32
60	1.00	40.8	1/330	1/100	27.5	33
50	1.50	36.1	1/330	1/100	25.7	29
40	2.25	32.1	1/330	1/100	24.0	25
30	3.50	29.1	1/330	1/100	22.8	22
20	6.00	26.4	1/330	1/100	21.5	19
10	13.00	23.2	1/340	1/100	20.3	13
0	∞	20.4	1/360	1/100	19.2	6

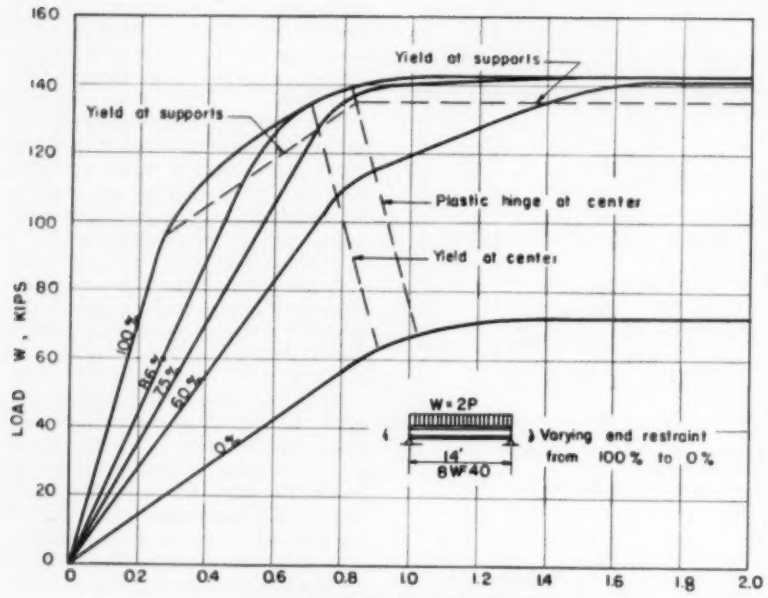


Fig. 18 Influence of end restraint on beam deflections

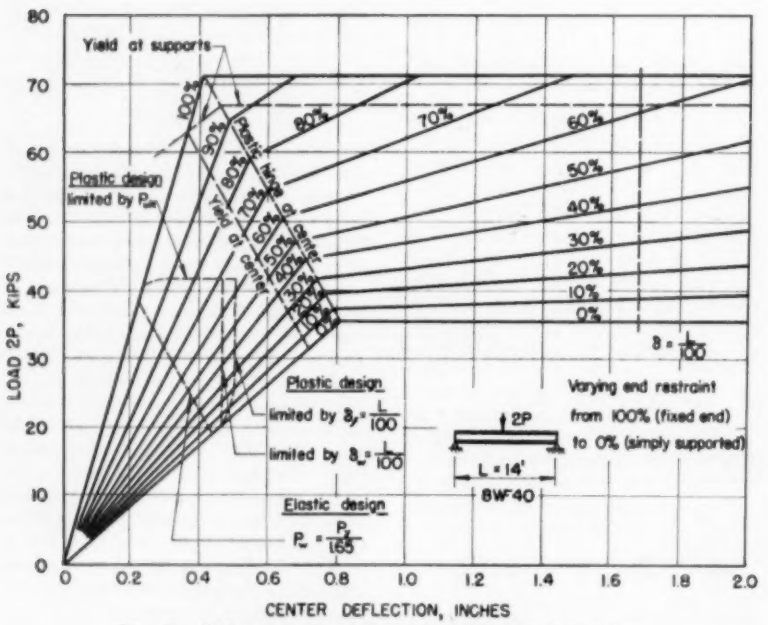


Fig. 19 Influence of end restraint on beam deflections

Table 3—Influence of the Distribution of the Load on the Strength and Deflection of a Continuous 8WF40 Beam with 75% End Restraint and 14-Ft Span

Load distribution	*Ultimate capacity*	*Deflection at ultimate load, in.*	*Deflection at 50 kips total load, in.*
Concentrated at center	71.3[b]	1.21	0.50
Third-point concentrated loads	106.9[b]	0.85	0.40
Uniformly distributed	142.6[b]	0.81	0.29

a rational measure of structural usefulness.

INFLUENCE OF LOAD DISTRIBUTION

A comparison between Figs. 16, 17 and 18 reveals how the distribution of a total load $2P$ influences the load-deflections relationship for continuous beams. In the three figures the load is concentrated at the center, divided between the third-points and uniformly distributed, respectively.

Concentrating the load near the beam center lowers the ultimate carrying capacity and increases the deflections. As an example some characteristic values from Figs. 16–18 are given in Table 3 for the beam with 75% end restraint ($L_1/L_2 = 1/2$). Twice the ultimate concentrated center load can be carried as uniformly distributed over the whole span, and causes a deflection of only two-thirds of that of the concentrated load.

For a certain load in the elastic range, say $2P = 50$ kips, the center deflection is increased from 0.29 to 0.50 in. by changing the load distribution from uniformly distributed to full concentration at the center point.

SUMMARY

1. In cases where the limitations imposed by local buckling, lateral buckling, etc., are met the following summary of this investigation of strength and deflections of continuous beams applies.

2. The plastic design of continuous beams and frames may require the calculation of critical deflections at the working load, and sometimes at the full load.

3. Several methods for predicting the load-deflection relationship of continuous beams are outlined. These methods are based on the moment-curvature relationship derived from the measured stress-strain relationship and differ only in the number of assumptions made to simplify the computation.

4. The simplest approach, the plastic hinge method, is most suitable for engineering applications. The additional work involved in the theoretically more "exact" methods is not justified by the accuracy gained except for special purposes.

5. Tests of as-delivered beams with welded details at supports and load points give larger deflections than predicted. The discrepancy probably is due to residual stresses and stress concentrations. Beams with regions of constant moment show the largest discrepancies (Figs. 10, 12, 14), while a cantilever gives good agreement with the predicted deflections (Fig. 11).

6. When the end restraint is small enough the full load predicted by the simple plastic theory is accompanied by excessive deflections (Figs. 16, 17, 18). The simple plastic theory may therefore have to be combined with a limitation on

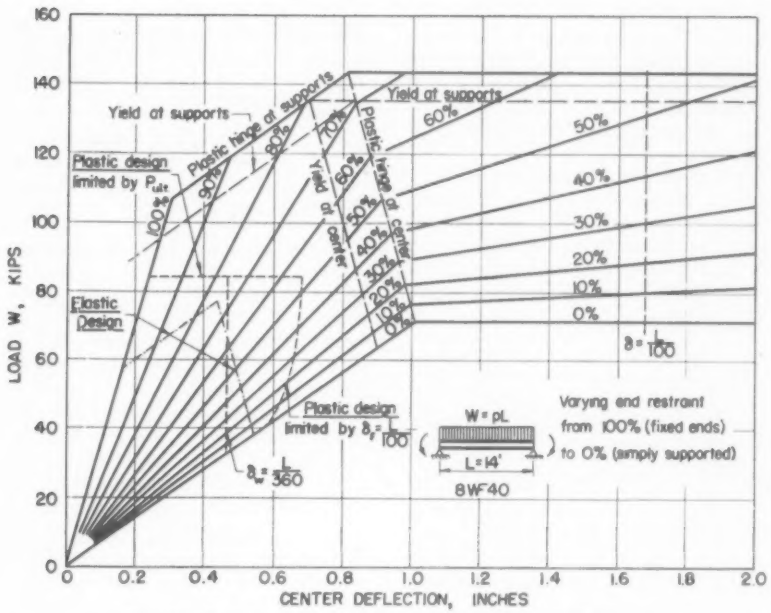


Fig. 20 Influence of end restraint on beam deflections

the deflections at the full load or a limitation on the deflection at working load. Continuous members having small end restraints are rare in engineering structures, however, and these deflection limitations may therefore be only of academic interest.

7. Whatever deflection limitations are established should provide a rational measure of structural usefulness.

8. A comparison of allowable load and resulting deflections of symmetrical continuous beams analyzed by elastic and plastic theory (Figs. 19 and 20) shows an increase in working load by the latter method of 0 to 29%, depending upon the end restraint and load distribution.

9. The effect of the load distribution may be demonstrated by the fact that the ultimate load of a uniformly loaded beam is twice that which can be applied concentrated at the center. The larger capacity obtained by distributing the load is accompanied by reduced deflections at the ultimate load (Table 3), except for the simple beam.

ACKNOWLEDGMENTS

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NOMENCLATURE

A = cross section area.
b = flange width.
B = strain-hardening offset: $M = BZ + CI\phi$.
C = strain hardening modulus.
E = modulus of elasticity.
f = shape factor, Z/S.
d = depth of section.
I = moment of inertia of cross section.
I_e = moment of inertia of elastic part of cross section.
l = length of plastic portion of beam.
L = span.
M = moment.
M_0 = useful ultimate load.
M_p = full plastic hinge moment, $\sigma_y \cdot Z$.
M_y = moment at initial yield, $\sigma_y \cdot S$.
P = concentrated load or total load on the span.
P_f = full load.
P_p = load causing yield through flanges at last hinge to form.
P_w = working load.
S = section modulus $2I/d$.
w = web thickness.
t = flange thickness.
x = distance along undeformed beam axis.
y_0 = distance from neutral axis to nearest fiber in yield.
y_ε = distance from neutral axis to nearest fiber in strain hardening.
Z = plastic modulus of cross section.
Z_e = plastic modulus of elastic part of cross section.
Z_p = plastic modulus of plastic part of cross section.
σ = unit normal stress.
σ_y = lower yield point stress.
ε = unit normal strain.
ϕ = curvature of bent member.
α = slope of deflected beam axis.
δ = deflection.
δ_f = deflection at full load.
δ_p = deflection due to P_p.
δ_w = deflection at working load.

APPENDIX

FLEXURE OF I SECTIONS ABOVE THE ELASTIC RANGE

by Walter H. Weiskopf

INTRODUCTION

For I sections in flexure in the elastic range the familiar expression $d^2y/dx^2 = M/EI$ applies, and its integrations provide the slope, the deflection curve, and the solutions of innumberable problems. In this appendix corresponding expressions are developed for I sections in the plastic and strain-hardening ranges and methods of integrating them are indicated.

Figure 21 shows the elastic, plastic and strain-hardening ranges of a specimen in tension. In flexure, however, the situation is more complicated. As load on a beam is increased, some of the fibers distant from the neutral axis and where the bending moment is great enter the plastic range. There are then two portions to the beam, one fully elastic and one in which the fibers far from the neutral axis are plastic. As the load is further increased, some of the fibers enter the strain-hardening range and there are then three portions of beam, one still elastic, one in which some of the fibers are plastic and one in which some of the extreme fibers are in the strain-hardening range. The plastic and strain-hardening sections will be analyzed separately.

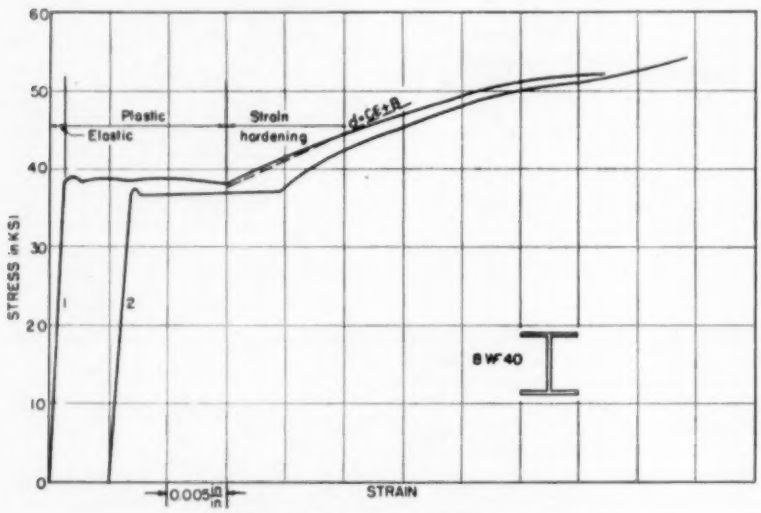

Fig. 21 Tension stress-strain curves

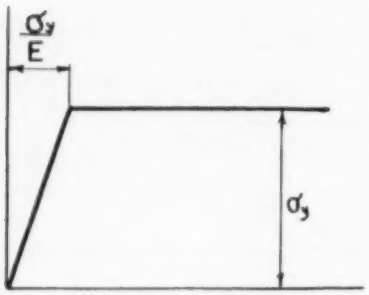

Figure 22

THE PLASTIC RANGE

The stress-strain diagram is idealized as shown in Fig. 22. Applied to an I section in flexure the strain and stress diagrams are shown in Figs. 23*a* and 23*b*. From Fig. 23*a* it is seen that the rotation per unit length of beam is

$$\phi = \frac{\sigma_y}{E y_0} \qquad (1)$$

Taking moments about the neutral axis in Fig. 23*b* there is obtained

$$M = \sigma_y \left(\frac{I_e}{y_0} + Z - Z_e \right) \qquad (2)$$

In this expression I_e is the moment of inertia and Z_e is the statical moment of the elastic portion of the cross section and Z is the statical moment of the entire cross section.

When the value of y_0 is such that the elastic portion of the cross section is entirely in the web, eq 2 becomes

$$M = \sigma_y \left(Z - \frac{y_0^2 w}{3} \right) \qquad (3)$$

In eq 3 w is the web thickness.

Eliminating y_0 from eqs 1 and 3

$$\phi = \frac{\sigma_y}{E} \sqrt{\frac{\sigma_y w}{3(\sigma_y Z - M)}} \qquad (4)$$

In eq 4 the expression $\sigma_y Z$ is the limiting value of the bending moment in which all of the fibers are stressed to the yield point as shown in Fig. 23*c*. This value, sometimes called the plastic hinge value, is designated M_p.

Then eq 4 becomes

$$\phi = \frac{\sigma_y}{E} \sqrt{\frac{\sigma_y w}{3(M_p - M)}} \qquad (5)$$

This is the fundamental relation of M to ϕ for the plastic range. In Fig. 24 this relation is plotted for an 8WF40. From the origin to point 1 the beam is elastic. From point 1 to point 2, y_0 is in the flange or fillet. To the right of point 2, y_0 is in the web and eq 5 applies. The portion 1 to 2 is a small portion of the useful range. To simplify the mathematics eq 5 will be extended to the left until it meets an extension of the elastic range at point 4. The value of the resisting moment at point 4, M_i, can be found by treating eq 5 simultaneously with the elastic expression $\phi = M/EI$.

$$3M_i^3 - 3M_p M_i^2 + I^2 \sigma_y^3 w = 0 \qquad (6)$$

M_i can be found by solving eq 6. It is a function of the cross section and σ_y only and can be tabulated for all beam sizes. The elastic range will then be taken from zero moment to M_i and the plastic range from M_i to M_p.

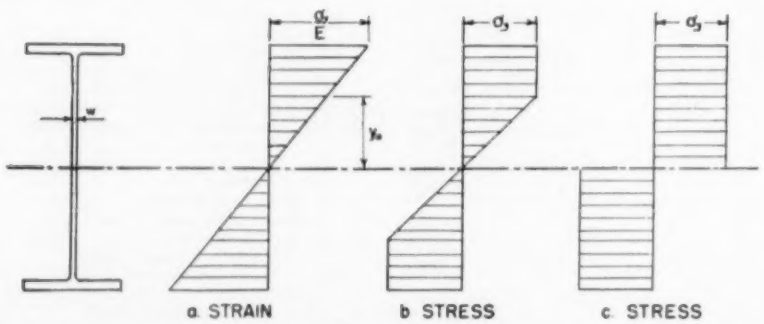

Figure 23

INTEGRATING THE M-ϕ CURVE (PLASTIC RANGE)

As is usually assumed in the theory of flexure d^2y/dx^2 is taken equal to ϕ and eq 5 becomes

$$\frac{d^2y}{dx^2} = \frac{\sigma_y}{E} \sqrt{\frac{\sigma_y w}{3(M_p - M)}} \qquad (7)$$

This expression must be integrated along

the length of the beam in the plastic range. For this integration M is a function of x and the remainder of the right-hand side of eq 7 is constant. The integrations have been performed for three cases: Fig. 25, the bending moment, M, is constant; Fig. 26, M follows a straight line variation (as between concentrated loads); Fig. 27, M follows a parabolic diagram (as for a uniform load). In these expressions, l is the length of the plastic portion which is generally only a small part of the total length of the beam.

The expressions first give the slope, dy/dx, and the deflection, y, at any point in the length. The constants of integration have been determined so as to give values in terms of the bending moments at the ends and the slope, α_L, and deflection, y_L, at the left end. Next (making $x = l$) the slope, α_R, and deflection, y_R, at the right end are obtained. Finally expressions for α_R and y_R are given for the special case, $M_L = M_p$ that is the full plastic range.

THE STRAIN-HARDENING RANGE

Above the plastic range the stress-strain curve again rises as shown in Fig. 21. It is assumed that the diagram follows a straight line in the strain-hardening range given by the equation

$$\sigma = C\,\epsilon + B \qquad (8)$$

C and B are constants of the material, C being analogous to E in the elastic range. For the steel shown in Fig. 21, C equals 667 kips per square inch and B equals 28 kips per square inch. Figure 28 represents the strain and stress diagrams for an I beam. From the figure

$$y_s = \frac{\sigma_y - B}{\sigma - B} \cdot \frac{d}{2} \qquad (9)$$

When the distance, y_s, is entirely in the web, the resisting moment of the cross section is

$$M = BZ + (\sigma - B)\frac{2I}{d} + \frac{1}{3}(\sigma_y - B)wy_s^2 \qquad (10)$$

In the right-hand member of eq 10 the first term covers the rectangle 0, 1, 4, 3; the second term the triangle 1, 5, 4 and the third term the triangle 1, 2, 6. Computations have shown this last term to be very small. If it is neglected eq 10 becomes

$$M = BZ + (\sigma - B)\frac{2I}{d} \qquad (11)$$

From Fig. 28

$$\phi = \frac{2\epsilon}{d} = \frac{2(\sigma - B)}{dC} \qquad (12)$$

Substituting $\sigma - B$ from eq 11 into eq 12

$$\phi = \frac{d^2y}{dx^2} = \frac{M - BZ}{IC} \qquad (13)$$

In Fig. 29 the relation of M to ϕ for an 8WF40 is again shown. This is similar to

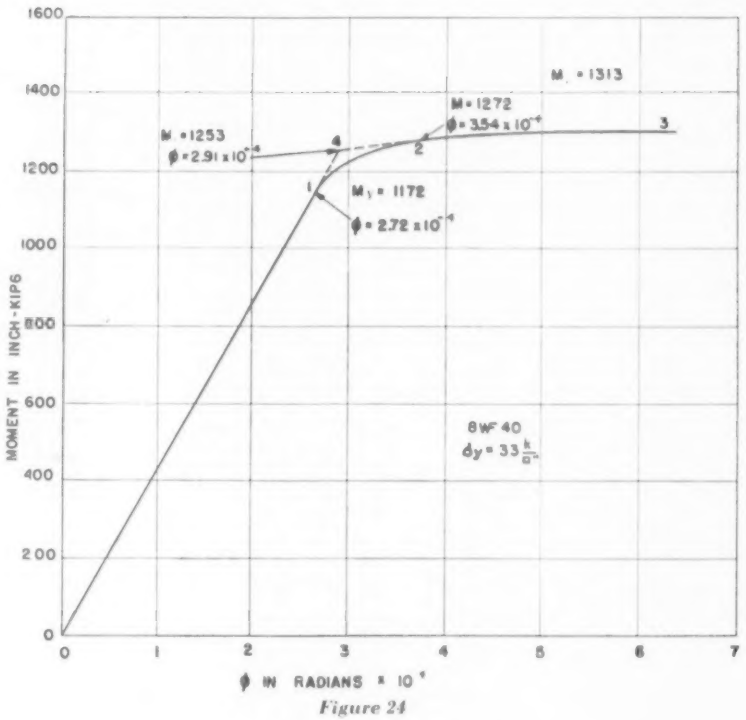

Figure 24

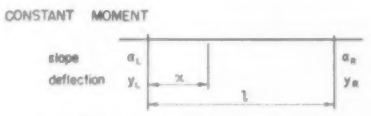

Fig. 25 See Equations 30 to 34

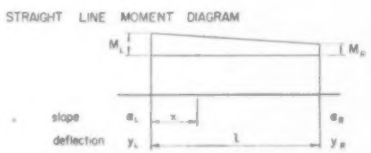

Fig. 26 See Equations 35 to 41

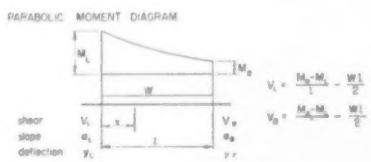

Fig. 27 See Equations 42 to 48

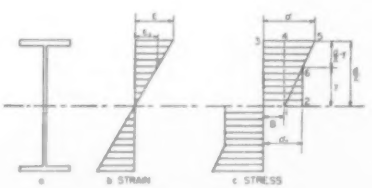

Figure 28

Fig. 24, but extended into the strain-hardening range. The solid line is the theoretical curve and the dotted line is eq 13.

It has been found that failure takes place before the stress gets very far into the strain-hardening range. Using the approximation of eq 13 therefore appears well justified.

In integrating eq 13 M is a function of x and the remaining symbols are constants. The integrations are so simple that they can be performed for each case without difficulty and will not be given here.

NUMERICAL EXAMPLE

To illustrate the method it will be applied to a beam with fixed ends and loads at the third points. This is Test B2[22] and is shown in Fig. 30. The following values are used:

8WF 40

I	= 146.3 in.^{4}	B	= 28 ksi
S	= 35.5 in.^{3}	C	= 667 ksi
Z	= 39.8 in.^{3}	L	= 168 in.
w	= 0.365 in.		

σ_y is taken as 37.6 ksi which is an average value of the test coupon results:

$M_y = 35.5 \times 37.6 = 1335''^k$

$M_p = 39.8 \times 37.6 = 1500''^k$

From eq 6

$$3M_L^3 - 3 \times 1500M_L^2 + 146.3^2 \times 37.6^2 \times 0.365 = 0$$

Solving this

$$M_L = 1433''^k$$

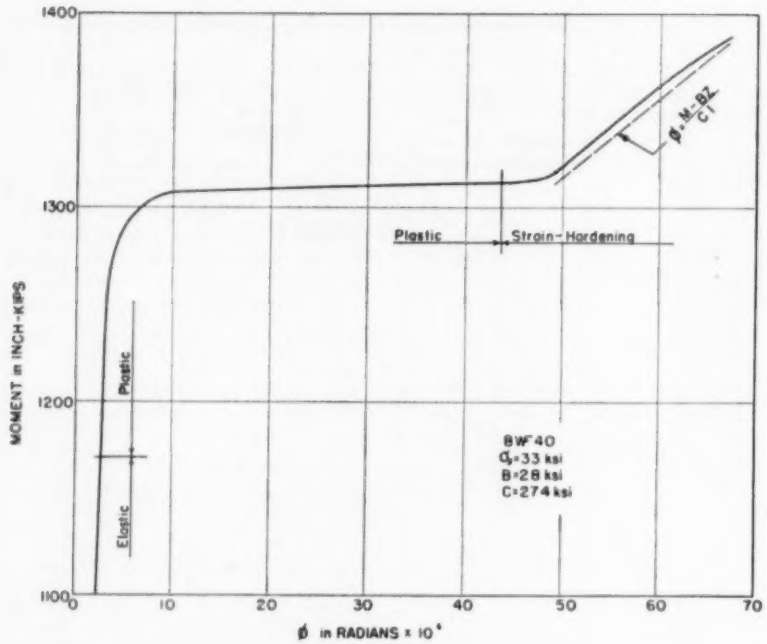

Figure 29

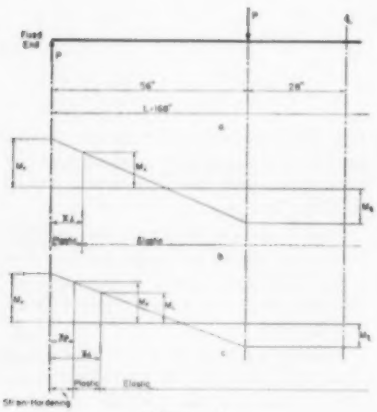

Figure 30

In the elastic range the fixed and moment is $2PL/9$ and the center moment $PL/9$.

Then

$$2PL/9 = M_i$$

$$P = \frac{9M_i}{2L} = \frac{9 \times 1433}{2 \times 168} = 38.4^k$$

This is the limiting load for the elastic range. For greater loads the ends of the beam enter the plastic range. The bending moment diagram for this condition is shown in Fig. 30*b*. The plastic section extends from the left end to the point where the bending moment equals M_i. The coordinate of this point is x_i. Treating the center section of the beam and the elastic portion of the left section (where x is greater than x_i) an expression for the slope can be found by the usual elastic theory. This is

$$\frac{dy}{dx} = \frac{1}{EI}\left[M_F\left(x - \frac{L}{2}\right) + P\left(\frac{L^2}{9} - \frac{x^2}{2}\right)\right] \quad (14)$$

The fixed end moment M_F is, of course, not the same as when the beam is entirely in the elastic range. In eq 14 it is unknown.

The slope where the elastic portion meets the plastic portion is found by putting x_i for x in eq 14.

$$\frac{dy}{dx}i = \frac{1}{EI}\left[M_F\left(x_i - \frac{L}{2}\right) + P\left(\frac{L^2}{9} - \frac{x_i^2}{2}\right)\right] \quad (15)$$

The slope at this point working from the left end of the beam through the plastic portion can be found by putting the proper values in eq 38. α_L equals zero since the beam is fixed at the end.

For M_R put M_i and for M_L put M_F. For l put x_i.

Then

$$\alpha_R = \frac{2\sigma_y}{E}\sqrt{\frac{\sigma_y w}{3}} \times \frac{x_i}{M_F - M_i} \times \left[\sqrt{M_p - M_i} - \sqrt{M_p - M_F}\right] \quad (16)$$

Obviously $(dy/dx)i$ of eq 15 must equal α_R of eq 16. Equating gives an expression in which x_i and M_F are unknown. From Fig. 30

$$x_i = \frac{M_F - M_i}{P} \quad (17)$$

Substituting this in eqs 15 and 16 equating the values, and simplifying there is obtained

$$\frac{2I\sigma_y}{P}\sqrt{\frac{\sigma_y w}{3}}\left[\sqrt{M_p - M_i} - \sqrt{M_p - M_F}\right] = \frac{M_F^2 - M_i^2}{2P} - \frac{M_F L}{2} + \frac{PL^2}{9} \quad (18)$$

For any load, P, eq 18 can be solved for the fixed end moment, M_F, by trial.

The largest value that P can have within the plastic range is that which makes the fixed end moment, M_F, equal to M_p. (This can be obtained by making M_F equal to M_p in eq 18 and solving for P.) The resulting equation is a quadratic and its solution is

$$P = \frac{9M_p}{4L} \pm \frac{3}{L} \times \sqrt{\frac{M_p^2}{16} + \frac{M_i^2}{2} + 2I\sigma_y\sqrt{\frac{\sigma_y w}{3}}(M_p - M_i)} \quad (19)$$

For the numerical example in Fig. 30 eq 19 gives $P = 41.0^k$ and $x_i = 1.63''$. This is the greatest value P can have before the fibers near the end of the beam enter the strain-hardening range. For this value of P the moment at the center of the beam is $800''^k$, well within the elastic range.

For values of P greater than 41.0^k the strain-hardening range is entered and the condition is that shown in Fig. 30*c*. The bending moment at any point in the end third is of course

$$M = M_F - Px \quad (20)$$

From the figure the following relations can be obtained:

$$x_i = \frac{M_F - M_i}{P} \quad (21)$$

$$x_p = \frac{M_F - M_p}{P} \quad (22)$$

$$x_i - x_p = \frac{M_p - M_i}{P} \quad (23)$$

The slope at any point on the elastic portion of the end third of the beam is again given by eq 14. The slope when x equals x_i can be found by putting x_i for x in this equation. Then using the value of x_i as given in eq 21

$$\frac{dy}{dx}i = \frac{1}{EI}\left[\frac{M_F^2 - M_i^2}{2P} - \frac{M_F L}{2} + \frac{PL^2}{9}\right] \quad (24)$$

For the plastic section eq 40 applies. α_R is given by eq 24 and M_R is M_i. l is $(M_p - M_i)/P$ as given by eq 23.

$$\alpha_L = -\frac{2\sigma_y}{E}\sqrt{\frac{\sigma_y w}{3}}\cdot\frac{\sqrt{M_p - M_i}}{P} + \frac{1}{EI}\left[\frac{M_F^2 - M_i^2}{2P} - \frac{M_F L}{2} + \frac{PL^2}{9}\right] \quad (25)$$

In the strain-hardening section, from eq 20

$$\frac{d^2y}{dx^2} = \frac{M - BZ}{CI} = \frac{1}{CI}\left[M_F - Px - BZ\right] \quad (26)$$

Integrating

$$\frac{dy}{dx} = \frac{1}{CI}\left[M_F x - \frac{Px^2}{2} - BZx + K\right] \quad (27)$$

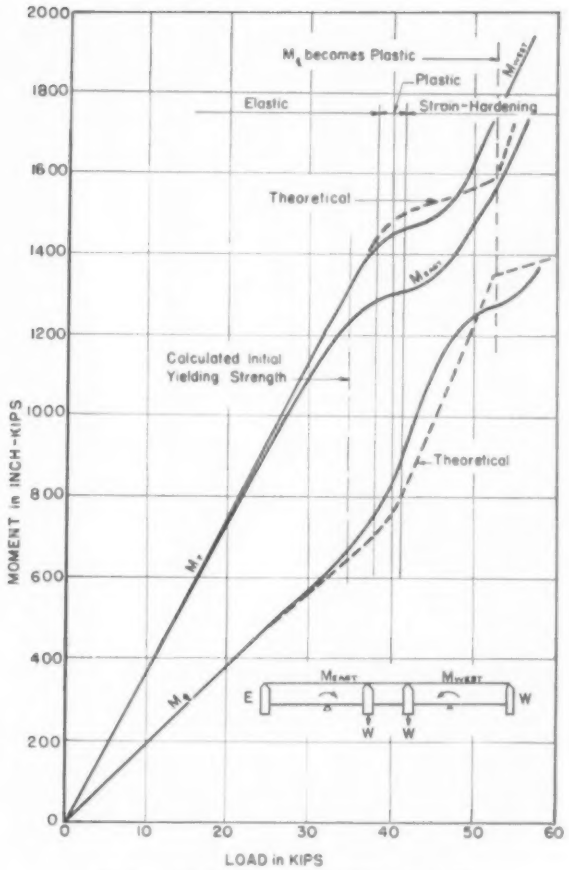

Fig. 31 Load-moment curves. Test B2

From the condition that $(dy/dx) = 0$ when $x = 0$ it is seen that the constant of integration, K, equals zero.

Putting x_p for x in eq 27 gives the slope where the plastic and strain-hardening sections meet. At this point, from eqs 27 and 22

$$\frac{dy}{dx} = \frac{1}{2CIP}[M_F^2 - M_p^2 - 2BZ(M_F - M_p)] \quad (28)$$

The slopes as given by eqs 28 and 25 must be the same. Equating them gives an expression that can be solved for M_F. It is

$$\left(-\frac{1}{C} + \frac{1}{E}\right)\frac{M_F^2}{2I} + \left(\frac{BZ}{CI} - \frac{PL}{2EI}\right)M_F - \frac{M_i^2}{2EI} + \frac{M_p^2}{2CI} + \frac{P^2L^2}{9EI} - \frac{BZM_p}{CI} - \frac{2\sigma_y}{E}\sqrt{\frac{\sigma_y w}{3}}\sqrt{M_p - M_i} = 0 \quad (29)$$

This is a quadratic and values of M_F can be computed without difficulty. Figure 31 shows the end and center moments for Test Specimen B2 as measured. The plotting extends through the elastic, plastic and strain-hardening ranges. A curve of values as given by the theory here presented is shown marked "Theoretical." Values were computed up to a loading which makes the center moment enter the plastic range. Beyond this point the end moments would turn upward and the center moment would flatten out.

BENDING ABOUT THE WEAK AXIS

For I sections subject to flexure about the weak axis all of the equations for the plastic range (Figs. 25, 26 and 27) can be used, if for the web thickness, w twice the flange thickness is used. These equations can also be used for rectangular sections if the width of the beam is used instead of the web thickness, w. The strain-hardening equations do not apply as accurately to the weak axis or to rectangular shapes. As a matter of fact, however, failure about the weak axis or in rectangular shapes is apt to take place before going far into the strain-hardening range if at all, so that for these cases M_p could be considered the ultimate bending moment.

(See Fig 25)

$$\frac{d^2y}{dx^2} = \frac{\sigma_y}{E}\sqrt{\frac{\sigma_y w}{3(M_p - M)}} \quad (30)$$

$$\frac{dy}{dx} = \frac{\sigma_y}{E}\sqrt{\frac{\sigma_y w}{3(M_p - M)}} \times x + \alpha_L \quad (31)$$

$$y = \frac{\sigma_y}{E}\sqrt{\frac{\sigma_y w}{3(M_p - M)}} \times \frac{x^2}{2} + \alpha_L x + y_L \quad (32)$$

For full length $(x = l)$

$$\alpha_R = \frac{\sigma_y}{E}\sqrt{\frac{\sigma_y w}{3(M_p - M)}} \times l + \alpha_L \quad (33)$$

$$y_R = \frac{\sigma_y}{E}\sqrt{\frac{\sigma_y w}{3(M_p - M)}} \times \frac{l^2}{2} + \alpha_L l + y_L \quad (34)$$

(See Fig 26)

$$\frac{d^2y}{dx^2} = \frac{\sigma_y}{E}\sqrt{\frac{\sigma_y w}{3}} \times \frac{1}{\sqrt{M_p - M_L + (M_L - M_R)\frac{x}{l}}} \quad (35)$$

$$\frac{dy}{dx} = \frac{2\sigma_y}{E}\sqrt{\frac{\sigma_y w}{3}} \times \frac{l}{M_L - M_R}\left[\sqrt{M_p - M_L + (M_L - M_R)\frac{x}{l}} - \sqrt{M_p - M_L}\right] + \alpha_L \quad (36)$$

$$y = \frac{4\sigma_y}{3E}\sqrt{\frac{\sigma_y w}{3}} \times \frac{l^2}{(M_L - M_R)^2}\frac{1}{l}\left[M_p - M_L + (M_L - M_R)\frac{x}{l}\right]^{3/2} - [M_p - M_L]^{3/2}\frac{l}{1} - \frac{2\sigma_y}{E}\sqrt{\frac{\sigma_y w}{3}} \times \frac{lx}{M_L - M_R}\sqrt{M_p - M_L} + \alpha_L x + y_L \quad (37)$$

For full length $(x = l)$

$$\alpha_R = \frac{2\sigma_y}{E}\sqrt{\frac{\sigma_y w}{3}} \times \frac{l}{M_L - M_R}\left[\sqrt{M_p - M_R} - \sqrt{M_p - M_L}\right] + \alpha_L \quad (38)$$

$$y_R = \frac{4\sigma_y}{3E}\sqrt{\frac{\sigma_y w}{3}} \times \frac{l^2}{(M_L - M_R)^2}[(M_p - M_R)^{3/2} - (M_p - M_L)^{3/2}] - \frac{2\sigma_y}{E}\sqrt{\frac{\sigma_y w}{3}} \times \frac{l^2}{M_L - M_R}\sqrt{M_p - M_L} + \alpha_L l + y_L \quad (39)$$

When $M_L = M_p$

$$\alpha_R = \frac{2\sigma_y}{E}\sqrt{\frac{\sigma_y w}{3}} + \frac{l}{\sqrt{M_p - M_R}} + \alpha_L \quad (40)$$

$$y_R = \frac{4\sigma_y}{3E}\sqrt{\frac{\sigma_y w}{3}} \times \frac{l^2}{\sqrt{M_p - M_R}} + \alpha_L l + y_L \quad (41)$$

(See Fig 27)

$$\frac{d^2y}{dx^2} = \frac{\sigma_y}{E}\sqrt{\frac{\sigma_y w}{3}}\frac{1}{\sqrt{M_p - M_L - V_L x - \frac{Wx^2}{2}}} \quad (42)$$

$$\frac{dy}{dx} = \frac{\sigma_y}{E}\sqrt{\frac{2\sigma_y w}{3W}}\left[\sin^{-1}\frac{Wx + V_L}{\sqrt{2W(M_p - M_L) + V_L^2}} - \sin^{-1}\frac{V_L}{\sqrt{2W(M_p - M_L) + V_L^2}}\right] + \alpha_L \quad (43)$$

$$y = \frac{\sigma_y}{E}\sqrt{\frac{2\sigma_y w}{3W}}\left[\frac{Wx + V_L}{W}\sin^{-1}\frac{Wx + V_L}{\sqrt{2W(M_p - M_L) + V_L^2}} - \right.$$

$$\left.\frac{Wx + V_L}{W}\sin^{-1}\frac{V_L}{\sqrt{2W(M_p - M_L) + V_L^2}} + \sqrt{\frac{2(M_p - M_L)}{W} - x^2 - \frac{2V_L x}{W}} - \sqrt{\frac{2(M_p - M_L)}{W}}\right] + \alpha_L x + y_L \quad (44)$$

For full length ($x = l$)

$$\alpha_R = \frac{\sigma_y}{E}\sqrt{\frac{2\sigma_y w}{3W}}\left[\sin^{-1}\frac{V_R}{\sqrt{2W(M_p - M_L) + V_L^2}} - \sin^{-1}\frac{V_L}{\sqrt{2W(M_p - M_L) + V_L^2}}\right] + \alpha_L \quad (45)$$

$$y_R = \frac{\sigma_y}{E}\sqrt{\frac{2\sigma_y w}{3W}}\left[\frac{V_R}{W}\sin^{-1}\frac{V_R}{\sqrt{2W(M_p - M_L) + V_L^2}} - \frac{V_R}{W}\sin^{-1}\times\right.$$

$$\left.\frac{V_L}{\sqrt{2W(M_p - M_L) + V_L^2}} + \sqrt{\frac{2(M_p - M_R)}{W}} - \sqrt{\frac{2(M_p - M_L)}{W}}\right] + \alpha_L l + y_L \quad (46)$$

When $M_L = M_p$

$$\alpha_R = \frac{\sigma_y}{E}\sqrt{\frac{2\sigma_y w}{3W}}\left[\sin^{-1}\frac{V_R}{V_L} - \frac{\pi}{2}\right] + \alpha_L \quad (47)$$

$$y_R = \frac{\sigma_y}{E}\sqrt{\frac{2\sigma_y w}{3W}}\left[\frac{V_R}{W}\sin^{-1}\frac{V_R}{V_L} - \frac{\pi V_R}{2W} + \sqrt{\frac{2(M_p - M_R)}{W}}\right] + \alpha_L l + y_L \quad (48)$$

(*Continued from page 223-s*)

all why this circumstance should "disprove rather than support" my thesis, and Dr. Polakowski does not reveal the reason for his assertion. Figure 16 of R. S. Brown's paper (*Jnl. Iron Steel Inst.*, **162,** 198 (1949)) shows strikingly that, for all strains above some $^1/_{10}\%$, the stress-strain curve of the cold drawn wire is high above that of the normalized wire, and its slope is of a higher order of magnitude. Thus, the relative position of the two curves corresponds fairly well to that of the two schematical curves in my Fig. 6. Of course, one must not mistake the anelastic behavior of the drawn wire at small strains for a sign of softness; it is due to internal stresses acquired during the drawing process.

The case of the Mount Hope suspension bridge has no direct relationship to the subject of fatigue. The wires initially used in this bridge were oil-hardened and tempered; they failed by what was essentially ordinary brittle fracture before the bridge was completed and subjected to substantial fluctuating loads.

Dr. Polakowski seems to have overlooked the circumstance that the quantity ϵ in the approximate relationship $\epsilon \cdot N \approx$ const. is the *plastic*, not the total (elastic plus plastic) strain. On the other hand, in empirical relationships such as $\epsilon^2 N \approx$ const., ϵ is the total strain calculated from the radius of the lip over which the wire or sheet is bent. With increasing lip radius, less and less of the total strain is plastic; this is the reason why the number of cycles to fracture is found to increase more rapidly than in inverse proportion to the total strain amplitude.

Owing to complex structural changes around the weld, experiments with welded specimens cannot be used for obtaining the fatigue behavior of a uniform material, and a welded specimen cannot be expected to obey the approximate relationship $\epsilon N \approx$ const. assumed for a homogeneous specimen.

If the material shows the yield phenomenon and develops Luders bands, the thin plastic layers in a bar bent just beyond its elastic limit do not run along the surface but at about 45 deg to it. In side view, they look like short whiskers growing obliquely into the bent bar from its top and bottom surfaces. Provided that they are thin and short, their position at 45 deg to the surface does not affect the argument in Fig. 17, nor the general treatment given in the paper. Large plastic and small elastic strains can alternate discontinuously in a deformed material (as in and around a Luders band) if their boundary runs along slip lines.

In his further objections to the considerations connected with Fig. 17, Dr. Polakowski has not taken into account that the points P and U *both* represent tensile stressing. The yield stress is reduced in the compressive half of the first cycle by the Bauschinger effect (this is shown in Fig. 17 by dashed lines), but it rises at least to the level of the point P in the first (tensile) half of the second cycle even if there is no strain aging. The experiment shown by Dr. Polakowski's Fig. 2, therefore, has no relevance to the argument given in Fig. 17. That strain aging at room temperature or above the blue-brittle range may be small or negligible is obvious; in a boiler or a chemical reaction vessel, however, it can be very important, and the considerations in Sect. 12 of my paper refer to such cases.

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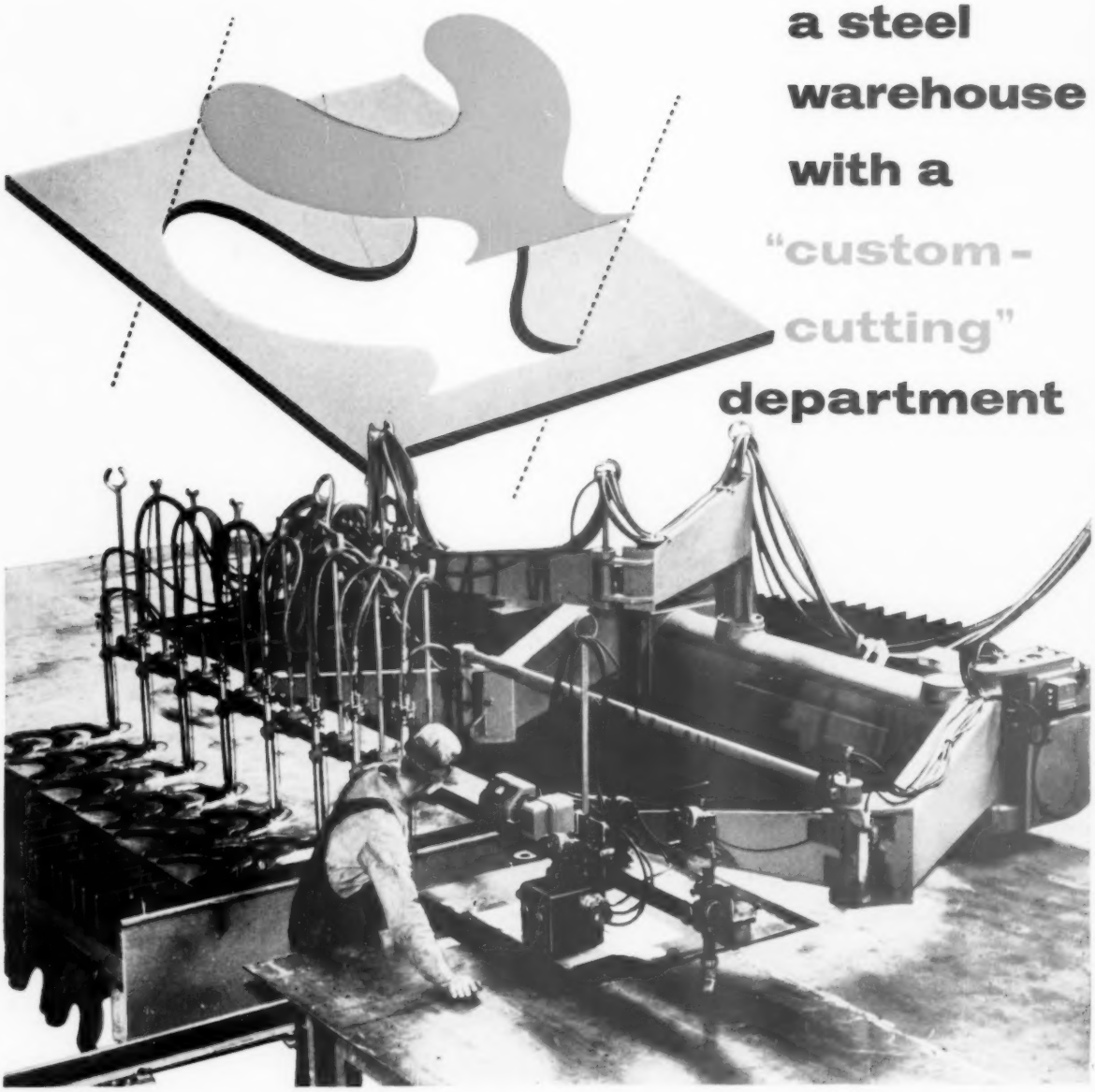

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